MONTHLY BULLETIN

OF THE

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

(ENGLISH EDITION)

PUBLISHING and EDITORIAL OFFICES: 231, RUE ROYALE, BRUSSELS.

Yearly prepaid subscription { **Belgium . . . . . 70 Belgas** / **Other countries . . 75 Belgas** } including postage

Price of this single copy: 12 Belgas (not including postage).

(1 Belga = 5 Belgian francs.)

Subscriptions and orders for single copies (January 1931 and later editions) to be addressed to the General Secretary, International Railway Congress Association, 231, rue Royale, Brussels (Belgium).

Orders for copies previous to January 1931 should be addressed to Messrs. Weissenbruch & Co. Ltd., Printers, 49, rue du Poinçon, Brussels.

Advertisements: All communications should be addressed to the Association, **231, rue Royale, Brussels.**

CONTENTS OF THE NUMBER FOR MARCH 1937.

CONTENTS.	Page.
I. **The construction of modern track to carry heavy loads at high speeds, and methods of modernising old track for such loads and speeds. Facing points which can be taken at high speeds** (Subject I, 13th Congress). Report (*America, Great Britain, Dominions and Colonies, China and Japan*), by T. YAMADA and Y. HASHIGUCHI	503
II. **Methods and devices used, in connection with electric traction, to save current between the supply side of the power station and the driving wheels (feeders, substations, tractors), and in particular the use of mercury rectifiers** (Subject VI, 13th Congress). Report (*Switzerland, France and Colonies, Spain, Portugal and Colonies, Italy, Belgium and Colony, Luxemburg, Netherlands and Colonies, Egypt*), by Messrs. EGGENBERGER and ECKERT	641
III. **Methods and devices used in connection with electric traction, to save current between the supply side of the power station and the driving wheels (feeders, substations, tractors), and in particular the use of mercury rectifiers** (Subject VI, 13th Congress). Report (*Austria, Germany, Denmark, Norway, Sweden, Finland, Poland, Hungary, Czechoslovakia, Bulgaria, Rumania, Greece, Turkey*), by E. R. KAAN	705
IV. **Specifications for the fixed plant of railways with light traffic, intended to prevent the use of unnecessarily expensive track equipment, and generally to give economical working** (Subject XIII, 13th Congress). Report (*Continental Europe and Colonies, Egypt*), by A. SVOBODA	759

CONTENTS (*continued*)

	Page.
V. **Methodical and periodical maintenance of : (1) metal bridges; (2) signals; (3) metal supports carrying the contact wire on electric railways.** — Organisation, working methods, materials used. (Subject III, 13th Congress). Report (*Netherlands and Colonies, Germany, Belgium and Colony, Luxemburg, Denmark, Norway, Sweden, Finland, Poland, Austria, Hungary, Switzerland*), by Th. W. Mundt	775
VI. Monthly Bibliography of Railways	31

LIBRARY

OF THE

Permanent Commission of the International Railway Congress Association.

READING ROOM : 231, rue Royale, Brussels.

Works in connection with railway matters, which are presented to the Permanent Commission, are mentioned in the « Bulletin ». They are filed and placed in the library. If the Executive Committee deems it advisable they are made the subject of a special notice. Books and publications placed in the reading room may be consulted by any person in possession of an introduction delivered by a member of the Association. Books, etc., may not be taken away except by special permission of the Executive Committee.

The Permanent Commission of the Association is not responsible for the opinions expressed in the articles published in the Bulletin.

All original articles and papers published in the BULLETIN are copyright, except with the consent of the Authors and the Committee.

Editions in **French** and in **German** are also published.

Vol. XIX. — No. 3. March 1937.

BULLETIN
OF THE
INTERNATIONAL RAILWAY CONGRESS
ASSOCIATION
(ENGLISH EDITION)

[625. 14]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

13th SESSION (PARIS, 1937).

QUESTION I.

The construction of modern track to carry heavy loads at high speeds, and methods of modernising old track for such loads and speeds.
Facing points which can be taken at high speeds.

REPORT

(America, Great Britain, Dominions and Colonies, China and Japan),

by T. YAMADA,
Director of the Bureau of Maintenance and Improvement, Japanese Government Railways,
and Y. HASHIGUCHI,
Chief of the Railway Research Office, Japanese Government Railways.

Introduction.

Subject I on the agenda of the 13th Session of the International Railway Congress Association is as follows: « The construction of modern track to carry heavy loads at high speeds, and the methods of modernising old track for such loads and speeds. Facing points which can be taken at high speeds. »

This report is a summary of replies received to the questionnaire which was sent to 110 Railway Administrations in the countries assigned to us. We take this opportunity to express our hearty thanks to these Railway Administrations for the valuable information they sent in.

* * *

PART I.

The construction of modern track to carry heavy loads at high speeds.

CHAPTER I.

Traffic and rolling stock.

(1) *Total weight (including weight of tender) and maximum axle loads of the*

heaviest locomotives for passenger and goods trains;

(2) *Respective maximum axle loads of passenger carriages and goods wagons;*

(3) *Maximum rigid wheel-base of the rolling stock;*

(4) *Maximum allowable operating speeds of passenger and goods trains on straight sections;*

(5) *Maximum train speed allowable for running over curves of different radii;*

(6) *Rules, if any, for the restriction of speed on curved tracks according to the amount of superelevation;*

(7) *Maximum allowable train speeds on different gradients;*

(8) *Gross tonnage (including weight of rolling stock) carried per year per track in the heaviest traffic section;*

(9) *The respective average frequencies of passenger and goods trains per day per track in the heaviest traffic section.*

The answers to these questions are summarised in Tables 1-A. and 1-B.

a) **Rolling stock** (table 1-A).

The maximum weight of passenger and goods locomotives of the standard and broad-gauge railways is 455 metric tons (Great Northern Railway) and 507 metric tons (Northern Pacific Railway) respectively. As for the narrow-gauge railways it is 174 metric tons (Central Cordoba Railway).

The maximum axle load of the standard and broad-gauge railways is 33.3 metric tons for passenger locomotives (Northern Pacific Railway) and 35.6 metric tons for goods locomotives (Reading Company). As regards the narrow-gauge railways it is 16.7 metric tons for passenger locomotives (Japanese Government Railways), and 16.7 metric tons for goods locomotives (Nigerian Railways).

The maximum axle load of passenger carriages on standard and broad-gauge railways is 24.5 metric tons (New York Central Lines). As for the narrow gauge, it is 11.2 metric tons (Japanese Government Railways).

The maximum axle loads of goods wagons on standard and broad-gauge railways is 27.2 metric tons (Canadian Pacific Railway, Pennsylvania Railroad and New York Central Lines), and that on narrow gauge is 13.3 metric tons (Japanese Government Railways).

The mean annual traffic carried by the first-class tracks is shown in Table 1-A.

The maximum annual tonnage per track of these Administrations is 40 000 000 tons for the New York Central Lines, 36 600 000 tons for the Norfolk and Western, and 32 722 000 for the Chesapeake and Ohio. As regards the narrow-gauge lines, it is 40 000 000 tons for the Japanese Government Railways.

The maximum train service frequency per day per track is 185 on the London and North Eastern Railway and 124 on the Great Indian Peninsula Railway. With the narrow-gauge lines, it is 225 trains (including 161 electric trains) on the Japanese Government Railways.

b) **The maximum allowable speed.**

The mechanical parts of each locomotive are designed to suit a certain limit of speed and a train shall not be permitted to run at a speed beyond this assumed maximum speed. Furthermore, in actual operation, the train speed is restricted on the curves and gradients, for fear of overturning or derailment.

The safe train speed allowable varies, however, with the gauge of the track, the height of the centre of gravity of the rolling stock, and the strength of the track. Each railway must determine the maximum operating speed, taking into consideration the above-mentioned conditions.

(1) **The maximum operating speed on the straight track.**

a) *Passenger trains.*

America. — The maximum operating speed for passenger trains on straight track is generally 96 km. (60 miles) to 128 km. (80 miles) per hour, with a single exception of 144 km. (90 miles) per hour for the diesel-electric locomotives of the Chicago, Burlington and Quincy Railway. Most of the Administrations covered by this report restrict their maximum operating speed to 112-120 km. (70 to 75 miles) per hour.

Great Britain, Dominions and Colonies. — Railways in Great Britain are operating many high-speed trains. The London Midland and Scottish Railway and the London and North Eastern Railway permit a speed of 144 km. (90 miles) per hour, and the Great Southern Railways (Ireland) 128 km. (80 miles) per hour. The Great Western Railway (Gr. Br.) and the Great Northern Railway set no restriction for the train speeds.

The maximum operating speed on the Canadian National Railways and the Canadian Pacific Railway is 120 km. (75 miles) per hour. On the railways of the other Dominions and Colonies trains are generally operated at speeds below 104 km. per hour.

Other countries. — The train speeds on the railways in other countries is under 100 km. (62 miles), per hour, such as 75 km. per hour on the Chinese National Railways, 100 km. on the Paulista Railway and 70 kilometres per hour on the Entre Rios Railway.

As regards the narrow-gauge railways, the maximum speed of passenger trains is under 80 km. per hour, with a single exception of 95 km. per hour on the Japanese Government Railways.

b) *Goods trains.*

America. — High-speed goods trains are often operated at speeds of 72 to 80 km. (45 to 50 miles per hour) and the maximum reported is 96 km. (60 miles) per hour on the Atlantic Coast Line.

Great Britain, Dominions and Colonies. — The maximum speed for goods trains is 88 km. (55 miles) per hour on the London and North Eastern Railway, the Great Western Railway and the London, Midland and Scottish Railway. Other Administrations permit only 80 km. (50 miles) per hour and under. This is rather a low speed in comparison with 144 km. allowed for passenger trains.

Other countries. — The maximum speed of goods trains on the Argentine and Brazilian Railways is 65 km (40.4 miles) per hour.

On narrow-gauge railways, the maximum speed is generally low; the highest allowed is 65 km. per hour (Japanese Government Railways).

As the design of the bogies or trucks, the spring gear and the height of the centre of gravity of passenger carriages are different from those of wagons, the operating speeds should differ accordingly.

(2) **The maximum operating speeds over curved track.**

The maximum train speeds over curved track are governed by the curvature of the latter and the amount of superelevation given.

The danger of vehicles overturning on curved track greatly diminishes when the outer rail is superelevated according to the operating speed thereon, but an excess of superelevation is liable to cause undue wear of the low rail, and in the worst case low-speed trains running over such curves tend to derail on the inside of the curve. It is, therefore, a general practice to limit the maximum amount of superelevation on the curved track, and at the same time the operating speed thereon is reduced sufficiently to avoid the high-speed train running uncomfortably owing to the lack of superelevation.

TABLE 1-A. — Rolling Stock.

RAILWAYS.	1	2		3		4		5	6	7	
	Gauge, metres, (ft. in.).	Maximum weight of locomotives (including tender), (tons).		Maximum axle load of locomotives (tons).		Maximum axle load of carriages and wagons (tons).		Maxim. rigid wheel-base (metres).	Gross tonnage carried per year per track in the heaviest traffic section (tons).	Average frequencies of trains per day per track in the heaviest traffic section.	
		Passenger trains.	Goods. trains.	Passenger trains.	Goods. trains.	Carriages.	Wagons.			Passenger trains.	Goods. trains.
Orient.											
Japanese Government Rys.	1.067 (3' 6")	...	...	...	...	...	...	...	...	...	...
Chosen Government-General Rys.	1.435 (4'81/2")	...	...	...	...	...	...	...	...	...	...
Chinese Rys.	1.435	289.67		22.00		15.50	15.00	...	...	22	12
Great Britain, Dominions and Colonies.											
London, Midland and Scottish Rys.	1.435	161.15	158.00	22.86	21.34	10.16	15.24	6.401	10 605 939	...	...
London and North Eastern Ry.	1.435	157.49	153.83	20.83	18.95	14.23	23.12	8.534	...	81	79
Great Western Ry. . . .	1.435	137.88	130.77	22.86	19.92	11.69	25.76	8.544	...	...	...
Southern Ry.	1.435	...	...	...	...	...	...	...	...	...	...
Great Northern Ry. . . .	1.600 (5' 3")	105.21	92.46	21.34	18.04	9.15	17.27	5.791	5 080 300	60	8
Great Southern Rys. . .	1.600	...	...	...	...	...	...	...	...	...	...
Canadian National Rys. .	1.435	302.32	...	27.22	...	13.61	22.68	6.604	15 240 900	30	
Canadian Pacific Ry. . .	1.435	324.78	334.62	28.55		18.14	27.22	6.020	6 604 390	16	8
North Western Ry. (India).	1.676 (5' 6")	179.03	177.23	20.12	19.31	13.21	16.26	4.877	4 379 219	20	
Great Indian Peninsula Ry.	1.676	124.98	162.57	21.85	21.34	...	...	6.096	...	114	10
East Indian Ry.	1.676	178.01	201.59	20.02	22.86	16.26	22.86	5.258	16 206 157	29.6	29.8
Madras and Southern Mahratta Ry.	1.676	157.49	162.57	17.78	17.27	16.26	16.26	6.096	4 161 782	12	5
Bengal Nagpur Ry. . . .	1.676	237.61		21.85		16.26	22.73	6.096	3 432 703	19	22
Burma Ry.	1.000	98.00	93.99	11.79	10.16	10.16	10.16	4.089	2 032 120	17.1	32.6
Ceylon Government Ry. .	1.676	118.88		15.75		5.08	5.33	2.896	1 016 379	33	2
New Zealand Government Rys.	1.067	148.35		15.09		8.13	9.65	4.343	2 947 945	15.5	11.1

New South Wales Government Rys.	1.435	161.55	230.65	20.47	23.12	17.38	17.78	4.572	Passenger : 2 400 000 Goods : 1 828 908	30	12
Sudan Government Rys. .	1.067	132.09		16.26		9.40	11.43	4.470	1 526 122	7	
Nigerian Rys.	1.067	109.73	141.99	13.16	16.77	8.13	12.55	...	508 030	48	
U.S.A.											
New York, Chicago and St. Louis R.R.	1.435	237.73	351.09	26.58	28.58	20.41	24.95	5.563	16 329 600	4	20
Southern Ry. System. . .	1.435	254.74	322.78	27.22	25.63	13.61	23.81	...	16 329 600	50	
Reading Co.	1.435	222.29	369.46	29.42	35.66	15.54	23.81	6.706	25 697 826	11.7	15.6
Northern Pacific Ry. . .	1.435	398.24	507.13	33.28	31.70	23.74	14.27	5.029	5 443 200	6	4
Atchison, Topeka and Santa Fe Ry.	1.435	197.59	227.98	32.48	34.70	15.78	6.76	3.353	14 515 200	6	13
Baltimore and Ohio R.R. .	1.435	246.76	333.35	30.85	31.68	12.33	...	6.807	21 163 067	12	19
New York, New Haven and Hartford R.R.	1.435	265.78	303.10	27.22	29.48	15.88	18.14	6.858	11 113 200	38	8
Chicago, Burlington and Quincy R.R.	1.435	368.20	407.29	31.95	33.02	13.15	18.14	6.807	9 979 200	34	
Norfolk and Western Ry. .	1.435	312.27	432.24	31.25	30.21	10.39	22.03	5.715	33 203 520	6	19
Delaware and Hudson R.R.	1.435	208.88	275.97	29.11	35.49	17.96	19.46	5.740	19 958 400	3	13
Chesapeake and Ohio Ry. .	1.435	389.51	444.98	31.03	34.02	14.97	23.81	7.417	29 685 398	1	9
Illinois Central R.R. . . .	1.435	256.74	305.73	27.67	28.31	15.42	22.68	6.807	16 329 600	11	20
Great Northern Ry. . . .	1.435	454.53		30.85		...	...	6.706	12 337 920	3	4
Atlantic Coast Line . . .	1.435	216.82	278.06	28.58	28.58	13.61	22.68	3.962	10 886 400	44	14
Florida East Coast Ry. .	1.435	261.91	277.56	24.77	27.81	14.06	23.13	5.969	...	14	3
Chicago, Rock Island and Pacific Ry.	1.435	336.62		30.22		...	...	6.858	9 072 000	36	
Pere Marquette Ry. . . .	1.435	321.59		27.94		13.88	23.81	6.858	9 072 000	7	15
New York Central Lines. .	1.435	299.10	313.70	29.39	28.58	24.49	27.22	5.486	36 288 000	25	
Pennsylvania R.R.	1.435	356.53		32.89		15.88	27.22	6.909	10 612 524	32.7	50.7
Missouri Pacific Lines . .	1.435	325.05	332.90	30.39	31.53	14.92	23.81	6.858	9 797 760	6.2	15.5
Southern Pacific Lines . .	1.435	333.71	424.34	30.39	31.53	14.06	12.78	5.105	...	...	...
Delaware, Lackawanna and Western R.R.	1.435	413.68		31.07	31.53	17.24	24.27	6.096	...	96	
Other Countries.											
Entre Rios Rys.	1.435	105.25		12.50		10.94	11.00	4.270	1 519 558	10	
Central Cordoba Ry. . . .	1.000	96.00	174.00	13.50	13.20	8.00	13.00	4.110	...	36	20
Paulista Ry.	1.600	152.00	129.10	20.10	18.60	13.70	15.30	4.572	...	12	21
Buenos Aires and Pacific Ry.	1.676	161.20	204.25	21.84	21.85	13.49	18.75	6.500	20 000 000	80	16

TABLE 1-B. — **Train speeds.**

RAILWAYS.	1	2		3			4
	Gauge, (metres).	Maximum allowable speed on the straight, km./h. *(m.p.h.)*.		Maximum allowable speed on curved sections. km./h. *(m.p.h.)*.			Maximum allowable speed on gradients. km./h. *(m.p.h.)*.
		Passenger trains.	Goods trains.				
Orient.							
Japanese Government Rys. . .	1.067	95 *(59)*	65 *(40.4)*	Radius.	Ordinary curve.	Turnout curve.	Flatter than 2 °/₀₀ 95 *(59.0)*
				600 m. *(30 chs.)*	85 *(52.8)*	65 *(40.4)*	6 °/₀₀ 90 *(56.0)*
				500 m. *(25 chs.)*	80 *(50.0)*	60 *(37.3)*	10 °/₀₀ 85 *(52.8)*
				450 m. *(22 1/2 chs.)*	75 *(46.6)*	55 *(34.2)*	14 °/₀₀ 80 *(50.0)*
				400 m. *(20 chs.)*	70 *(43.5)*	55 *(34.2)*	18 °/₀₀ 75 *(46.6)*
				350 m. *(17 1/2 chs.)*	65 *(40.4)*	50 *(31.0)*	20 °/₀₀ 70 *(43.5)*
				300 m. *(15 chs.)*	60 *(37.3)*	50 *(31.0)*	25 °/₀₀ 65 *(40.4)*
				250 m. *(12 1/2 chs.)*	55 *(34.2)*	45 *(28.0)*	30 °/₀₀ 50 *(31.0)*
				200 m. *(10 chs.)*	50 *(31.0)*	45 *(28.0)*	35 °/₀₀ 45 *(28.0)*
				175 m. *(8 3/4 chs.)*	45 *(28.0)*	40 *(25.0)*	
				150 m. *(7 1/2 chs.)*	40 *(25.0)*	35 *(21.7)*	
				125 m. *(6 1/4 chs.)*	35 *(21.7)*	30 *(18.6)*	
				less than 100 m. *(5 chs.)*	30 *(18.6)*	25 *(15.5)*	
Chosen Government-General Rys.	1.435	...	...	...			...
Chinese Rys.	1.435	75 *(46.6)*	...	Speed corresponding to the maximum superelevation of 125 mm.			...
Great Britain, Dominions and Colonies.							
London, Midland and Scottish Ry.	1.435	144.9 *(90)*	...	603 m. *(30 chs.)*	96.6 *(60)*		...
				845 m. *(42 chs.)*	112.7 *(70)*		
				1 085 m. *(54 chs.)*	128.6 *(80)*		
				1 368 m. *(68 chs.)*	144.9 *(90)*		
London and North Eastern Ry.	1.435	144.9 *(90)*	88.5 *(55)*	$V = 11 \sqrt{R}$ V = speed, m.p.h. R = radius, chains. Maximum superelevation is 152 mm. (6").			...

Great Western Ry.	1.435	...	88.5 *(55)*-48.3 *(30)*	...	...	
Southern Ry.	1.435	...	...	...	...	
Great Northern Ry.	1.600	...	40.2 *(25)*	...	...	
Great Southern Rys.	1.600	128.8 *(80)*	...	...	...	
Canadian National Rys. . . .	1.435	120.8 *(75)*	80.5 *(50)*	...	...	
Canadian Pacific Ry. . . .	1.435	»	72.4 *(45)*	...	...	
North Western Ry. (India) .	1.676	96.6 *(60)*	...	...	The same as the level section.	
Great Indian Peninsula Ry. .	1.676	104.6 *(65)*	56.3 *(65)*	$V = \sqrt{R-235}$ (without transition curve). $V = 1\ 1/4 \sqrt{R-235}$ (with transition curve). V = maximum speed, m/h. R = radius of curve, feet.	Maximum speed 40.2 *(25)* on 1/37 gradient.	
East Indian Ry.	1.676	96.6 *(60)*	48.3 *(30)*-64.4 *(40)*	...	1/72 1/80	48.3 *(30)* 64.4 *(40)*
Madras and Southern Mahratta Ry.	1.676	104.6 *(65)*	64.4 *(40)*	...	...	
Bengal Nagpur Ry.	1.676	96.6 *(60)*	56.3 *(35)*	...	...	
Burma Ry.	1.000	72.4 *(45)*	56.3 *(35)*	...	...	
Ceylon Government Ry. . . .	1.676	64.4 *(40)*	...	101 m. *(5 chs.)* — 24.2 *(15)* 201 m. *(10 chs.)* — 32.2 *(20)* 402 m. *(20 chs.)* — 40.2 *(25)*	1/44	24.2 *(15)*
New Zealand Government Rys.	1.067	80.5 *(50)*	56.3 *(35)*	Over 422 m. *(21 chs.)* — 80.5 *(50)* 402 to 322 m. *(20 chs. to 16 chs.)* — 72.4 *(45)* Under 302 m. *(15 chs.)* — 64.4 *(40)*	...	
New South Wales Government Rys.	1.435	112.7 *(70)*	64.4 *(40)*	201 m. *(10 chs.)* — 51.5 *(32)* 402 m. *(20 chs.)* — 80.5 *(50)* 603 m. *(30 chs.)* — 99.8 *(62)* Over 764 m. *(38 chs.)* — 112.7 *(70)*	...	
Sudan Government Rys. . . .	1.067	70	...	...	70	
Nigerian Rys.	1.067	64.4 *(40)*	...	No restriction till R = 291 m.; from R = 291 m. to 175 m. (least radius), reduced gradually to 32.2 *(20)*.	...	
U.S.A.						
New York, Chicago and St. Louis R.R.	1.435	112.7 *(70)*	80.5 *(50)*	Standard of A.R.E.A.	...	
Southern Ry. System	1.435	...	...	...	...	

TABLE 1-B *(Continued)*.

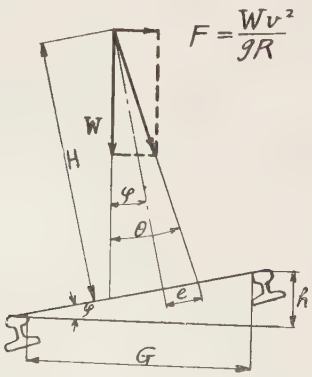
RAILWAYS.	1	2		3			4	
	Gauge,	Maximum allowable speed on the straight, km./h. *(m.p.h.)*.		Maximum allowable speed on curved sections.			Maximum allowable speed on gradients.	
	(metres).	Passenger trains.	Goods trains.	km./h. *(m.p.h.)*.			km./h. *(m.p.h.)*.	
Reading Co.	1.435	128.8 *(80)*	72.4 *(45)*	873 m. (2°)	No restriction		22 °/₀₀	24.8 *(15.4)*
				873 m. (2°) to 437 (4°)	88.5 *(55)*		32 °/₀₀	12.9 *(8)*
				437 m. (4°) to 250 (7°)	80.5 *(50)*			
Northern Pacific Ry.	1.435	96.6 *(60)*	80.5 *(50)*	Over 437 (4°)	No restriction		On down gradients of 22.5 °/₀₀ : Goods trains 32.2 *(20)* Passenger trains 48.3 *(30)*	
				437 (4°)	72.4 *(45)*			
				349 (5°)	64.4 *(40)*			
				291 (6°)	56.3 *(35)*			
				250 (7°)	48.3 *(30)*			
				218 (8°)	40.2 *(25)*			
				194 (9°)	36.2 *(22.5)*			
				175 (10°)	32.2 *(20)*			
				159 (11°)	28.2 *(17.5)*			
				146 (12°)	24.2 *(15)*			
Atchison, Topeka and Santa Fe Ry.	1.435	...	...	On steep gradients about 48.3 *(30)*.			...	
Baltimore and Ohio R.R. . .	1.435	120.8 *(75)*	80.5 *(50)*	1 746 m. (1°)	120.8 *(75)*		On long gradients : 15 °/₀₀ 72.4 *(45)* 20 °/₀₀ 56.3 *(35)*	
				873 m. (2°)	120.8 *(75)*			
				582 m. (3°)	112.7 *(70)*			
				437 m. (4°)	96.6 *(60)*			
				349 m. (5°)	88.5 *(55)*			
				291 m. (6°)	80.5 *(50)*			
				250 m. (7°)	72.4 *(45)*			
				218 m. (8°)	72.4 *(45)*			
				194 m. (9°)	64.4 *(40)*			
				175 m. (10°)	64.4 *(40)*			
				159 m. (11°)	56.3 *(35)*			
				146 m. (12°)	56.3 *(35)*			
New York, New Haven and Hartford R.R.	1.435	112.7 *(70)*	80.5 *(50)*	112.7 *(70)* till R = 873 m. and the maximum superelevation is 152 mm. (6").			112.7 *(70)*	
					Steam.	*Diesel.*	...	
Chicago, Burlington and Quincy R.R.	1.435	Diesel 144.9 *(90)* Steam 112.7 *(70)*	80.5 *(50)*	1164 m. *(1° 30')*	112.7 *(70)*	144.9 *(90)*		
				1164 *(1° 30')* to 873 *(2°)*	104.6 *(65)*	136.8 *(85)*		
				873 *(2°)* to 582 *(3°)*	88.5 *(55)*	104.6 *(65)*		

Norfolk and Western Ry. . .	1.435	112.7 *(70)*	80.5 *(50)*	...	...	72.4 *(45)*
Delaware and Hudson R.R. .	1.435	Main line 120.8 *(75)* Branch line 72.4 *(45)*	48.3 *(30)*	...	16 °/₀₀	32.2 *(20)*
Chesapeake and Ohio Ry. . .	1.435	120.8 *(75)*	72.4 *(45)*	Standard of A.R.E.A.	...	
Illinois Central R.R.	1.435	128.6 *(80)*	80.5 *(50)*	...	...	
Great Northern Ry.	1.435	56.3 *(35)*- 104.6 *(65)*	32.2 *(20)*- 64.4 *(40)*	Over 437 m. — No restriction 437 to 291 — 48.3 to 80.5 291 to 218 — 48.3 to 64.4 218 to 166 — 48.3	...	
Atlantic Coast Line	1.435	112.7 *(70)*	96.6 *(60)*	582 m. — 112.7 *(70)* 437 m. — 96.6 *(60)* 349 m. — 80.5 *(50)* 291 m. — 72.4 *(45)* 250 m. — 64.4 *(40)* 218 m. — 56.3 *(35)* 194 m. — 48.3 *(30)* 175 m. — 32.2 *(20)*	...	
Florida East Coast Ry. . .	1.435	104.6 *(65)*	72.4 *(45)*	437 m. — 88.5 *(55)* 349 m. — 72.4 *(45)* 291 m. — 64.4 *(40)* 250 m. — 56.3 *(35)* 218 m. — 48.3 *(30)* 194 m. — 40.2 *(25)* 175 m. — 24.1 *(15)*	...	
Chicago, Rock Island and Pacific Ry.	1.435	112.7 *(70)*	...	Standard of A.R.E.A.	112.7 *(70)*	
Pere Marquette Ry.	1.435	112.7 *(70)*	80.5 *(50)*	104.6 *(65)*, usually 80.5 *(50)*.	...	
New York Central Lines . .	1.435	128.6 *(80)*	80.5 *(50)*	...	16 °/₀₀ 6 °/₀₀	48.3 *(30)* 112.7 *(70)*
Pennsylvania R.R..	1.435	120.8 *(75)*	80.5 *(50)*	...	...	
Missouri Pacific Lines . . .	1.435	120.8 *(75)*	80.5 *(50)*	...	...	
Southern Pacific Lines . . .	1.435	...	...	...	...	
Delaware. Lackawanna and Western R.R.	1.435	112.7 *(70)*	...	...	...	
Other Countries.						
Entre Rios Rys.	1.435	70	50	...	...	
Central Cordoba Ry.	1.000	50	...	...	...	
Paulista Ry.	1.600	100	65	...	...	
Buenos Aires and Pacific Ry.	1.676	70 actually 100	40 actually 60	...	...	

Both the centrifugal force and the guiding action due to the turning of the vehicles running over a curved track cause an appreciable lateral thrust on the higher rail, and the magnitude on these forces increases in proportion to the square of the velocity. The lateral thrust overcomes the friction between rail and wheel as the speed increases, and at last the vehicles overturn or derail on the outside of the curve.

Some Railway Administrations determine the maximum allowable speed on curves according to the radius of the curves without any regard to the amount of superelevation given. Other Railways decide the maximum speed for each curve taking into account the amount of superelevation. In both cases the maximum speeds on curves are determined as a general rule by experience rather than calculated theoretically.

It is most desirable to maintain train speeds over curves within limits corresponding to the superelevation provided, so that the resultant of the weight of the vehicle and the centrifugal force passes through the centre line of the track. But in fact such an ideal case cannot always be expected to occur and the deviation of the resultant is inevitable, especially with the track which takes both the high and low-speed trains.



The deviation e is given by the following formula :

$$e = H \tan (\Theta - \varphi)$$
$$= H \frac{\tan \Theta - \tan \varphi}{1 + \tan \Theta \tan \varphi}$$

The values of Θ & φ being very small,

$$e \doteq H \left(\tan \Theta - \tan \varphi \right)$$
$$\tan \Theta = \frac{v^2}{g\,R}$$
$$\tan \varphi = \frac{h}{G}$$

where

H = height of centre of gravity of vehicle above rail level in metres,
g = acceleration of gravity (9.8 m./sec.^{2}),
R = radius of curve, in metres,
v = running speed in metres per sec.
V = running speed in kilometres per hour,
h = superelevation in metres,
G = gauge in metres,

$$e = H \left(\frac{v^2}{g\,R} - \frac{h}{G} \right)$$
$$= H \left(\frac{V^2}{127\,R} - \frac{h}{G} \right).$$

When the value of e is equal to $\frac{G}{2}$ the vehicles overturn. On many railways the running speeds are so restricted that the value of e may be $\frac{1}{f} \cdot \frac{G}{2}$, f being the factor of safety for overturning.

The factor of safety f is calculated by the following formula :

$$f = \frac{G}{2} \cdot \frac{1}{e}$$

or

$$e = \frac{G}{2f}$$

$$\frac{G}{2f} = H \left(\frac{V^2}{127\,R} - \frac{h}{G} \right)$$

$$V = \sqrt{127\,R \left(\frac{G}{2\,f\,H} + \frac{h}{G} \right)}$$

$$f = \frac{G}{2\,H} \cdot \frac{1}{\left(\frac{V^2}{127\,R} - \frac{h}{G} \right)}.$$

Among the Railway Administrations which determine the maximum allowable speed over curves without regard to the amount of superelevation are the Japanese Government Rys, Ceylon Government Ry., New Zealand Government Rys., London, Midland and Scottish Ry., London and North Eastern Ry., New South Wales Government Rys., Great Indian Peninsula Ry. and Northern Pacific Ry. Most of these Administrations decide the maximum allowable speed in such a manner that the factor of safety remains 3 to 5, even in the case of $h = 0$, which is the most dangerous case. Some Administrations demand a safety factor as high as 10 or over.

According to the London and North Eastern Ry., the allowable speed is as follows :

$$V = 11 \sqrt{R},$$

where

V = speed in miles per hour,
R = radius of curve in chains.

The factor of safety derived from the above formula is 3.00 to 3.26. The Great Indian Peninsula Ry. uses the following formula :

$$V = \sqrt{R-235},$$

where

V = speed in miles per hour,
R = radius of curve in feet,

the safety factor being 6 or over in this case.

The majority of Railway Administrations in the United States adopt the A. R. E. A. formula for the running speed over curves, by which the resultant of the gravity and centrifugal force passes within the middle third of the gauge. The factor of safety against overturning obtained from this formula is 6.

In the United States, most railways prohibit passenger trains from exceeding a comfortable speed, which corresponds to a superelevation 3″ higher than the actual elevation of the outer rail.

In this case, the safety factor against overturning for existing locomotives is about 7.

(3) The maximum allowable speed over gradients.

Trains running over a gradient, especially over a descending gradient, should restrict their speed for the sake of safe operation, taking their braking effects into account. The braking distance varies with the kind of brakes fitted, and consequently the maximum allowable speeds over gradients on various railways greatly differ from each other. At present not only passenger trains, but also goods trains are fitted with the countinuous brake, and the compressed-air brake takes the place of the hand brake. In fact, many Administrations do not restrict the speed on gradients, but in the case of a down gradient where the slope is steeper than 1.5 %, the operating speed must be restricted, because speed control in such a section is quite difficult.

* * *

CHAPTER II.

Track stresses.

(1) *Formulæ for calculating track stresses;*

(2) *Dynamic augments of track stresses due to the train speed;*

(3) *Maximum unit stresses allowable for rails and rail supports.*

For the safe operation of heavy trains at high speeds, track components, i.e. rails, sleepers, ballast and roadbed, must be able to bear train loads at their highest speeds. Therefore, it is necessary to calculate track stresses and maintain the actual track stresses within the permissible limits. Many Railway Administrations are now investigating these problems.

Methods of calculating track stresses have been evolved by many authors. Zimmermann's theoretical solution, and its application deduced by the Special Committee on Stresses in Track set up by the American Society of Civil Engineers (A.S.C.E.) and the American Rail-

way Engineering Association (A.R.E.A.) as well as the results of experiments carried out by this Committee, are all quite instructive. The Committee is now proceeding with its work, and the results which have already been published are useful for calculating the strength of the track and the effect of the rolling loads on it. For example, the design of locomotives, especially the wheel arrangement and the distribution of counterbalance weights of the driving wheels, may be determined so as to reduce the track stresses caused by these locomotives to a minimum. The Japanese Gofernment Rys. have carried out research work on the track stresses during the last ten years, made many experiments in connection with such stresses and derived many solutions therefrom. By the use of these solutions, stresses in rails, sleepers, roadbed and fish-plates are easily calculated, the strength of the track is determined and the maximum wheel load and allowable speed are decided in theory.

We deem it useful to touch briefly upon the formulæ adopted and the results of the experiments carried out by, the Japanese Government Rys., and the Special Committee on stresses in track (U. S. A.).

A. — Formulæ worked out and experiments carried out by the Special Committee on Stresses in Track (U.S.A.).

Reports on track stresses by the Special Committee on stresses in track, set up jointly by the A.S.C.E. and A.R.E.A. have been published in the *Bulletin* of the A. R. E. A., Vol. 19 (1918), Vol. 21 (1920), Vol. 23 (1922), Vol. 26 (1925), and Vol. 31 (1930). The outlines of these reports are as follows :

a) Fundamental equations.

It is assumed that the rail is supported continuously on an elastic support and that the support has a constant modulus of stiffness, that is, the depression of the track and the resulting upward pressures on the rail are directly proportional to each other. It is further assumed that the track construction is such that negative pressures may be developed under the same conditions of elasticity as are the positive pressures.

The following nomenclature is used :

- P = weight of wheel load on rail at the point which will be used as the origin of the abscissa;
- E = modulus of elasticity of steel;
- J = moment of inertia of a section of the rail;
- y = depression of rail at any point x, it being assumed that there is no play in the track. Downward displacement of rail is taken as negative. However, in their application to track, the ordinary downward depressions of track will be spoken of as positive;
- y_0 = depression of rail at the point under the wheel load ($x = 0$);
- p = upward pressure against rail per unit of length of rail at any given point;
- p_0 = upward pressure against rail per unit of length of rail at the given wheel load ($x = 0$);
- u = elastic constant which denotes the pressure per unit of length of each rail, necessary to depress the track [rail, sleeper (tie), ballast, and roadbed], by one unit. For the system of units ordinarily used it will be expressed in pounds per inch of length of rail required to depress the track one inch. The value of u represents the stiffness of the track and involves conditions of tie, ballast and roadway. It is termed the modulus of elasticity of rail-support.
- M = bending moment in rail at any point;
- M_0 = bending moment in rail at the point of wheel load due to single wheel load ($x = 0$).
- x_1 = distance from the wheel load to the point of zero bending moment in the rail;

x_2 = distance from the wheel load to the point of zero upward pressure. It will be shown that x_2 is $3x_1$;

e = base of the natural system of logarithms = 2.7183.

For a single wheel load the equation for the depression of the rail at any point x is as follows.

$$y = -\frac{P}{\sqrt[4]{64\,EJ\,u^3}}\,e^{-x\sqrt[4]{\frac{u}{4\,EJ}}}\left(\cos x\sqrt[4]{\frac{u}{4\,EJ}} + \sin x\sqrt[4]{\frac{u}{4\,EJ}}\right) \quad . \quad . \quad (1)$$

The bending moment developed in the rail at any point x is given by the following equation :

$$M = EJ\frac{d^2y}{dx^2} = P\sqrt[4]{\frac{EJ}{64\,u}}\,e^{-x\sqrt[4]{\frac{u}{4\,EJ}}}\left(\cos x\sqrt[4]{\frac{u}{4\,EJ}} - \sin x\sqrt[4]{\frac{u}{4\,EJ}}\right) . \quad (2)$$

The equation for intensity of pressure against the rail is

$$p = -u\,y \quad . \quad . \quad . \quad . \quad (3)$$

the expression for y being given in equation (1). The following special values of the functions will be found useful :

The distance from the wheel load to the point of zero bending moment in the rail [$M = 0$ in equation (2)] is

$$x_1 = \frac{\pi}{4}\sqrt[4]{\frac{4\,EJ}{u}} \quad . \quad . \quad . \quad (4)$$

The value of the maximum bending moment in the rail (which is at the wheel load) [$x = 0$ in equation (2)] is

$$M_0 = P\sqrt[4]{\frac{EJ}{64\,u}} = 0.318\,P\,x_1 \quad . \quad (5)$$

The value of the maximum track depression (which is at the wheel load) [$x = 0$ in equation (1)] is

$$y_0 = -\frac{P}{\sqrt[4]{64\,EJ\,u^3}} \quad . \quad . \quad (6)$$

The value of the maximum intensity of upward pressure (which is at the wheel load) [$x = 0$ in equation (3)] is

$$p_0 = P\sqrt[4]{\frac{u}{64\,EJ}} = -u\,y_0 \quad . \quad (7)$$

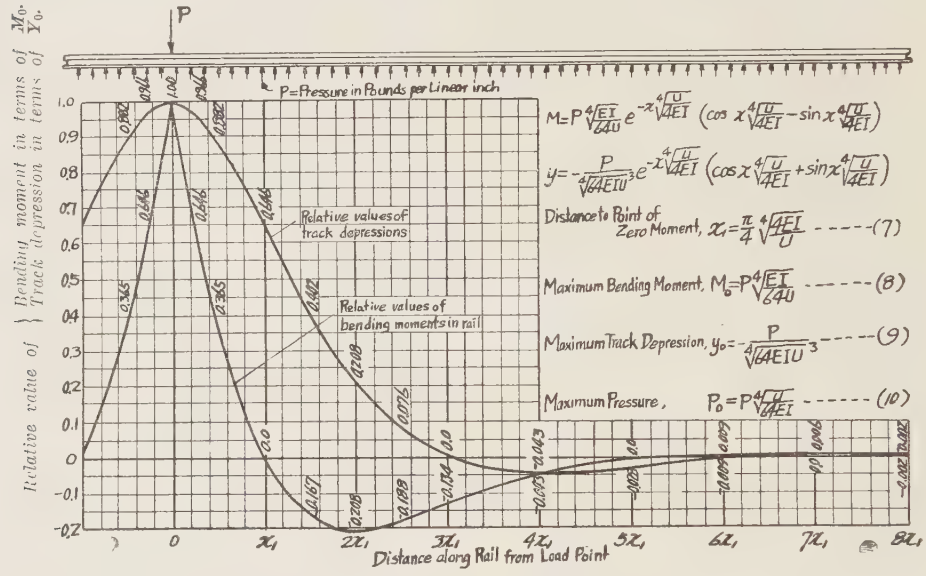
The distance from the wheel load to the point of zero upward pressure on the rail [$p = 0$ in equation (3)] is

$$x_2 = \frac{3\pi}{4}\sqrt[4]{\frac{4\,EJ}{u}} = 3\,x_1 \quad . \quad (8)$$

The master diagram, figure 1, gives coefficients of (1) the moment developed in the rail, and (2) the intensity of pressure against the rail and the depression of the rail as determined by the foregoing equations. In using this diagram the value of the maximum bending moment M_0 may be computed by equation (5), and the distance x_1 to the point of zero bending moment by equation (4). The bending moment at any given point is then found by multiplying the value of the maximum bending moment M_0 by the ordinate found in the diagram corresponding to the ratio of x to x_1. Similarly, the value of the rail depression at any point or that of the intensity of pressure may be determined by multiplying the rail depression or the intensity of pressure under the wheel load by the ordinate for pressure at the given point.

To find the effect of a combination of wheel loads upon track depression, pressure and the bending moment in a rail, as may occur with a given type of locomotive or a group of vehicle wheels, the values found from the equations and dia-

Fig. 1. — Master diagram for :
(1) Moment developed in the rail, and
(2) Intensity of pressure against the rail, and depression of the rail, single-wheel load.


P
P=Pressure in Pounds per Linear inch
Relative values of track depressions
Relative values of bending moments in rail
Relative value of { Bending moment in terms of M_o / Track depression in terms of Y_o
Distance along Rail from Load Point
$M=P\sqrt[4]{\frac{EI}{64u}}e^{-x\sqrt[4]{\frac{u}{4EI}}}\left(\cos x\sqrt[4]{\frac{u}{4EI}}-\sin x\sqrt[4]{\frac{u}{4EI}}\right)$
$y=-\frac{P}{\sqrt[4]{64EIu^3}}e^{-x\sqrt[4]{\frac{u}{4EI}}}\left(\cos x\sqrt[4]{\frac{u}{4EI}}+\sin x\sqrt[4]{\frac{u}{4EI}}\right)$
Distance to Point of Zero Moment, $x_1=\frac{\pi}{4}\sqrt[4]{\frac{4EI}{u}}$ ----(7)
Maximum Bending Moment, $M_o=P\sqrt[4]{\frac{EI}{64u}}$ ------(8)
Maximum Track Depression, $y_o=-\frac{P}{\sqrt[4]{64EIu^3}}$ ----(9)
Maximum Pressure, $P_o=P\sqrt[4]{\frac{u}{4EI}}$ ------(10)

grams derived for a single wheel load may be utilized by means of the principle of superposition, i.e., by considering that at any given point along the rail the combined effect of two or more wheel loads is the algebraic sum of the effects of individual wheel loads. The effect that each wheel load produces at any given point may be determined from the master diagram (fig. 1), and the cumulative effect of the several loads may then be found by adding algebraically the component magnitudes produced by each wheel load.

b) Value of the modulus of elasticity of rail support (u).

The value of u differs according to weight of rail, spacing and size of sleepers, and hardness of roadbed. The measured value of u on different railways is as follows :

On the Illinois Central R.R., with 85-lb. per yd. rails and sleepers of 6″ × 8″ × 8′ 0″ size, the spacings of which are 22″, the value of u was between 1 000 and 1 600 lb./in².

In an A-class track of the Chisago, Milwaukee, St. Paul and Pacific R.R., with 100-lb. rails and sleepers of 6″ × 8″ × 8′ 0″ size, their spacing being 20″, the value of u was 2 000 lb./in²; In a B-class track of the same Railroad with 75-lb. rails, and with sleepers of 6″ × 8″ × 8′ 0″ size, spaced 20″, the value of u was found to be 900-lb./in².

c) Increase of stresses in rail due to speed of train.

The stresses in rail increase rapidly with the increase of locomotive speed. The Committee has analysed these phenomena from two aspects, i.e. the effects of the counterbalancing of driving wheels and the effects of speed. When the counterbalance weights of driving wheels — applied to balance the rotating and reciprocating parts of driving

wheels — exceed or are under the necessary weight (generally below requirements in the case of the main driving wheels, and in excess for other wheels), the centrifugal forces due to the unbalanced weights have marked effects on rails, and the magnitude of this action varies the relative position of the counterbalance to the axes. With over-balanced driving wheels, the maximum stress occurs when the counterbalance takes the lowest position, then it becomes smaller as the counterbalance raises its position. The minimum occurs when the counterbalance takes the highest position; average values of the maximum and minimum stresses give stresses which include no effect of unbalanced weights, and the difference between the maximum and average values shows the effect of unbalanced weight. At the speed of 5 m.p.h., the average and maximum values are almost equal, and the effect of unbalanced weight is negligible. The value of stress at this speed, S 5, can be considered as the value of stress for stationary loads. When the speed increases, both the average stress S_m and the maximum value S_v increase. The Committee has used the following nomenclature :

$\frac{S_m}{S_5}$: effect of speed;

$\frac{S_v - S_m}{S_5}$: effect of counterbalance;

$\frac{S_v}{S_5}$: total effect or combined effect of speed and counterbalance.

Experimental measurements taken on actual tracks showed that these effects vary within wide ranges with the kind of locomotive and the arrangement of the driving wheels. The measured values of the maximum rate of increase for various kinds of locomotives are shown in Table 2.

TABLE 2. — **Increment of stresses.**

Railway.	Type of locomotive.	Speed, V, (miles per hour).	Maximum effect of speed, $\frac{S_m}{S_5}$	Maximum effect of counterbalance, $\frac{S_v - S_m}{S_5}$	Maximum total effect, $\frac{S_v}{S_5}$
St. Louis San Francisco.	*Santa Fe* (before reconstruction).	50	1.98	1.83	3.75
Do.	*Santa Fe* (after reconstruction).	50	2.09	1.59	3.68
Do.	*Pacific.*	60	1.44	0.44	1.88
Illinois Central.	*Mikado.*	45	1.49	0.67	2.14
Atchison, Topeka and Santa Fe.	*Pacific.*	60	1.30	0.29	1.53
Do.	*Light Prairie.*	50	1.26	0.33	1.43
Do.	*Mountain.*	60	1.30	0.21	1.55
Do.	*Light Santa Fe*	45	1.77	1.13	2.90
Do.	*Heavy Santa Fe*	40	1.28	0.43	1.80
Delaware and Hudson.	*Pacific.*	60	1.24	0.35	1.59

Excepting several kinds of locomotives, the increment of stresses caused by speed only at the maximum speed is under 30-50 % compared with the stresses at 5 m.p.h., and the effect of the counterbalance is 30-40 %. The latter has a tendency to increase rapidly when the train speed exceeds the designed or allowable speed.

The total effect is 50-100 %, and this value varies widely according to the kind of locomotive. The *Santa Fe* type of the St.Louis, San Francisco Ry. has shown 3.68-3.75 times 5 miles/hr., which proves that the design of locomotives, and especially the distribution of weight on the driving wheels bears intimate relation to the track stress.

Stresses caused by leading and trailing wheels have no effect of unbalanced weight and they are affected only by speed. The ratio of increase of stresses caused by leading and trailing wheels is less than that of driving wheels and is generally 20-30 % for trailing, 40-60 % for leading, and 40-60 % for tender wheels, at the maximum speed.

d) Lateral stresses in straight track.

Generally, on a straight track, the stresses in the outer flange of the rail base are larger than the stresses in the inner flange, which shows that the wheel pressure has a horizontal component besides a vertical one, and pushes the rail to the outer side of the gauge.

The ratio of the stress in the outer flange of the rail base to the average stress is about 1.1-1.2, and rarely exceeds 1.3. Blind driving wheels exert less horizontal pressure upon the rail than ordinary driving wheels.

e) Stresses in the rail on curved track.

When trains run over a curved track at speeds lower than that for which the outer rail is superelevated, the load on the inner rail is greater than that on the outer rail, and as the speed increases the excess load moves to the latter. As has been proved by many experiments, the load distribution of locomotives calculated from the measured values of the vertical bending stresses of the inner and outer rails coincides with the theoretically calculated value. But the value of vertical bending stresses under each driving wheel widely differs from the theoretical value, and sometimes the stresses under some driving wheels become extraordinarily large.

The lateral pressure necessary for guiding locomotives along curves occurs generally between the front outer driving wheel and the outer rail, and sometimes lateral pressure of the outer leading wheel aids this action. The centre of rotation of locomotives is situated about the rearmost inner driving wheel, or in some cases at the next driving wheel from the rearmost one, and the lateral pressure is greatest at this centre of rotation. With locomotives running at lower speed the amount of lateral bending stress in the rail at the rear inner driving wheel is quite great, but as the speed increases, the stress under the inner driver decreases and the lateral bending stress under the front outer driving wheel increases rapidly.

The ratio of the lateral to the vertical bending stresses differs according to the design of locomotives, i.e. according to the total wheel-base, distribution of wheel loads, distances between drivers, rigidity of the frame, amount of curve superelevation given, and the running speed. The maximum values measured on the test track are shown in Table 3.

TABLE 3.

Ratio of lateral bending stress to vertical bending stress under locomotive driving wheels.

Radius, metres (degr.).	Rail.	Ratio of lateral bending stress to vertical bending stress (%)	
		steam locomotive.	electric locomotive.
291 m. (6°)	inner rail	60-80	30-50
	outer rail	40-70	40-65
175 m. (10°)	inner rail	50-85	30-80
	outer rail	40-85	45-60

Generally speaking, the maximum lateral bending stress occurs under the driver which gives the maximum vertical bending stress. Therefore, the maximum bending stresses in the curved track are greater than those on the straight.

f) **Distribution of pressure in the ballast.**

When pressure p_a per unit length of a sleeper acts upon the top surface of the ballast, pressure p at any point in the ballast is represented by the following formula :

$$p = \frac{k\, p_a}{\sqrt{\pi}}\, e^{-k^2 x^2},$$

where

x = horizontal distance between line of pressure and the point where the pressure is calculated,

h = vertical distance between the surface, and the point considered,

k = function of h, and is determined by experiment.

Experimental measurements taken with sleepers of 200 mm. (8″) width, have shown that the value of p may be calculated by the following empirical formula, when the depth of the ballast ranges between 100 mm. (4″) and 750 mm. (30″).

$$p = \frac{16.8\, p_a}{h^{1.25}}(10)^{-6.05 \frac{x^2}{h^{1.5}}},$$

where

p_a = mean pressure intensity per unit area under sleeper,

h, x = measured in inches.

Pressure intensity directly under a sleeper is represented as follows :

$$p = \frac{16.8\, p_a}{h^{1.25}}.$$

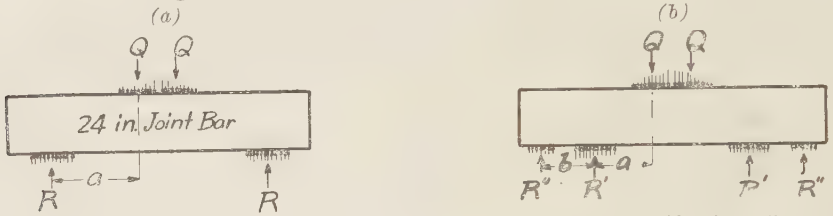
g) **Stresses in fish-plates.**

Under vertical loads, fish-plates act as simple beams supported at both ends on rail bases and loaded at the middle point by loads from the rail heads. The points of action of these forces depend on the condition of the contact surfaces between rails and fish-plates, but as a rule, the centres of pressure situate 25 mm. (1″) apart from the rail ends, and the centres of reaction lie 180-200 mm. (7″-8″) from the rail ends in the case of fish-plates of 60-70 cm. (24″-27″) length. Sometimes there is another centre of reaction several inches away from the first centre, as illustrated in Figure 2, but the magnitude of the pressure at the second centre is much smaller than the first. In the second case the centre of R′ is about 11.5 cm. (4 1/2″) apart from the centre of Q, while the centre R″ is 10 cm. (4″) from R′.

The maximum bending moment in fish-plates occurs at the middle section;

its value does not exceed 85 % of the bending moment in the corresponding rail section. The ratio of the maximum bending moments of a pair of fish-plates to the rail under the same load is called the « joint moment ratio » and its

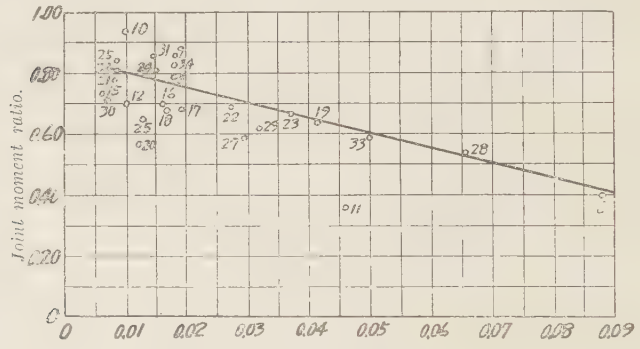
Fig. 2. — Load bearings and reaction on fish-plates.



Single centroid of reaction bearings for positive moment.

Double centroids of reaction bearings for positive moment.

Fig. 3. — Joint moment ratio and numerical sum of vertical movements between fish-plate and rail, for 26 joints.



Numerical sum of vertical movements in inches (Av. of both fish-plates).

numerical value is inversely proportional to the sum of plays between contact surfaces of fish-plates and rails. Figure 3 shows the relation of the sum of plays at the four contact surfaces between fish-plates and rail, and joint moment ratio.

When the maximum bending moment of the fish-plate is small, it shows that a few sleepers near the joint support the wheel load on the joint, which is not a desirable feature as regards maintenance. The play between rails and fish-plates becomes smaller as bolts are tightened up, while the joint moment ratio becomes larger.

The tightening up of the end bolts of fish-plates causes especially favourable results.

Symmetrical fish-plates, such as the flat bar type, have a horizontal neutral axis through the centre of gravity of the section under vertical loads, so that the stresses in the section are proportional to the distances from this horizontal axis. But the stresses in the section of unsymmetrical fish-plates are not proportional to the distances from a horizontal axis.

Figure 4 shows the results of the test, and also that the stresses are proportional to distances from an inclined neutral axis having an inclination of 38° to the horizontal.

Fig. 4. — Stresses observed in angle fish-plate, plotted with reference to horizontal axis and to inclined axis.

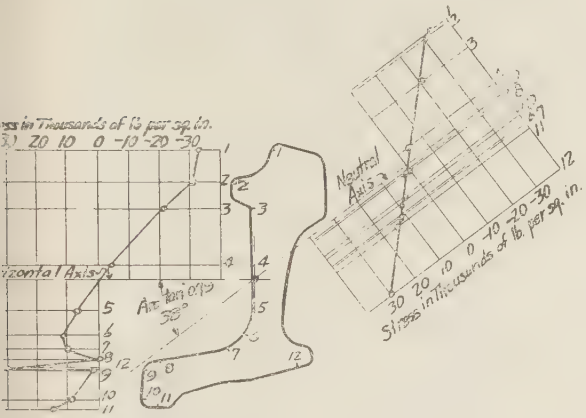
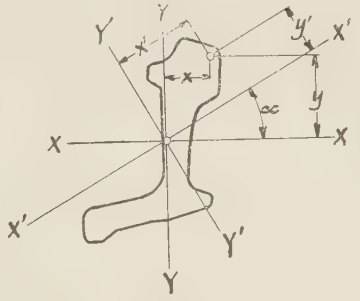


Fig. 5. — Diagram showing co-ordinates for analysis of dissymmetrical type of fish-plate.



In Figure 5, X-X and X-Y are horizontal and vertical axes passing through the centre of gravity, X′-X′ the neutral axis, and Y′-Y′ the axis perpendicular to the neutral axis X′-X′.

If

M_x = bending moment around the X-axis,

M_y = bending moment around the Y-axis,

S = stress at (x, y) or (x', y'),

a = infinitesimal area of the section,

α = angle between the neutral and horizontal axes,

then

$$S = q\, y'$$

$$y' = (y - x \tan \alpha) \cos \alpha = y \cos \alpha - x \sin \alpha$$

$$Mx = \Sigma\, q\, y'\, y\, a = \Sigma\, q\, y^2\, a \cos \alpha - \Sigma\, q\, xy\, a \sin \alpha = q\, Jx \cos \alpha - q\, Jxy \sin \alpha$$

where J_x = moment of inertia around X-axis;
J_{xy} = product of inertia about X and Y axes.

$$q = \frac{S'}{y'} = \frac{S}{(y - x \tan \alpha) \cos \alpha}$$

$$Mx = \frac{Jx - Jxy \tan \alpha}{y - x \tan \alpha} S = \frac{Jx \cos \alpha - Jxy \sin \alpha}{y \cos \alpha - x \sin \alpha} S,$$

similarly

$$My = \frac{Jxy - Jy \tan \alpha}{y - x \tan \alpha} S$$

$$\frac{My}{Mx} = \frac{Jxy - Jy \tan \alpha}{Jx - Jxy \tan \alpha} = \tan \lambda$$

$$\tan \alpha = \frac{Jxy - Jx \tan \lambda}{Jy - Jxy \tan \lambda} = \frac{Jx - Jxy \cot \lambda}{Jxy - Jy \cot \lambda}.$$

As J_x, J_y, and J_{xy} are constants for the fish-plate under consideration, the inclination of the neutral axis α can be calculated.

In the case of free bending, that is when M_Y is zero, the value of α of an unsymmetrical angle-type fish-plate is 50°-53°, but in practice friction between

rails and fish-plates, tension of bolts, etc. give a lateral resisting moment and the value of α becomes 33°-45°.

The maximum stress in the fish-plates with an inclined neutral axis is much greater than that with a horizontal neutral axis, the value in the former case sometimes being 60 % larger than the latter.

These investigations have led to the design of a new type of fish-plate. It is now general practice to adopt a symmetrical type and make the angle of inclination of the neutral axis as small as possible. Some Railway Administrations improved their old angle-type fish-plates, by curtailing the outer flange of the base of the angle, and increasing the width of the base to the inner side, thus reforming the bar to an I-section. This improvement does not imply any remarkable variation of the original area or the section modulus, but the value of J_{xy} becomes small and the maximum stress in the cross section is decreased by 15-20 %.

Fig. 6. — Ratio of maximum stress at given inclinations of neutral axis to maximum stress for horizontal position of neutral axis.

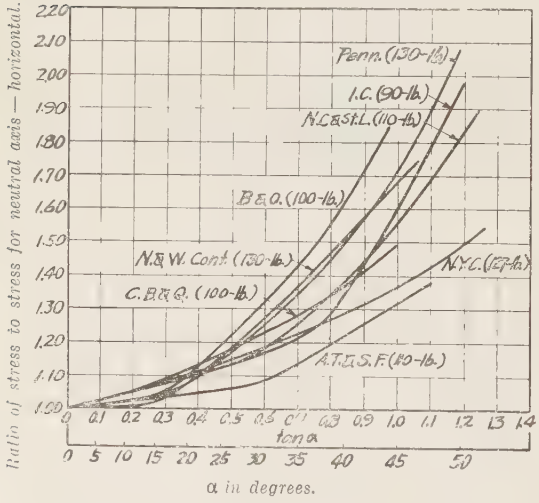


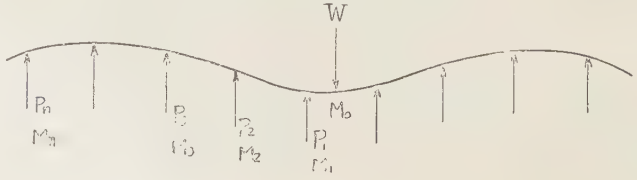
Figure 6 shows the relation between the inclination of the neutral axis and the maximum stress, and that the maximum stress increases rapidly when the inclination of the neutral axis α exceeds a certain critical value.

B. — Formulæ for calculating track stresses, established by the Japanese Government Railways.

The Japanese Government Railways have established formulæ for calculating stresses in the track, after many years' study on this subject. Formulæ for calculating stresses in rails, fish-plates, roadbed, in a straight or curved track, as well as the dynamic augment due to train speeds will be briefly described.

a) Fundamental formulæ for the calculation of track stresses.

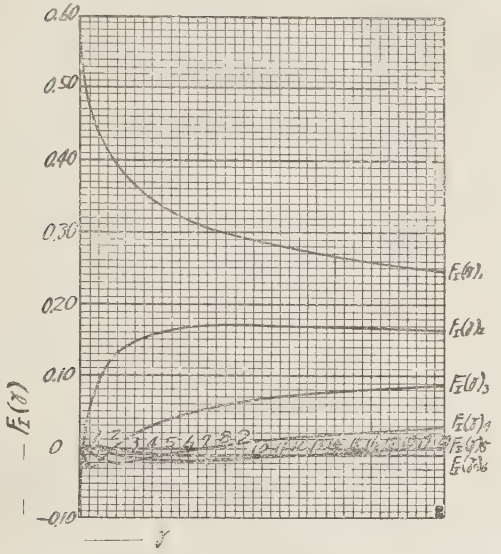
It is assumed that an indefinitely long continuous jointless rail is supported by uniformly spaced sleepers; the sleepers are depressed in proportion to the rail pressure applied to them, and bear the negative pressure in the same proportion. Then, when a single wheel load W is applied at the middle point between two adjacent sleepers, the bending moment at any point of the rail M, and the reaction of any sleepers P calculated by the *three moment theorem* are as follows (for the explanation of notations, see figures) :



$$\left.\begin{aligned} P_1 &= F_I(\gamma)_1 W \\ P_2 &= F_I(\gamma)_2 W \\ &\cdots\cdots\cdots \\ P_n &= F_I(\gamma)_n W \end{aligned}\right\} \quad \ldots \quad (1)$$

$$\left.\begin{aligned} M_0 &= F_{II}(\gamma)_0 a W \\ M_1 &= F_{II}(\gamma)_1 a W \\ &\cdots\cdots\cdots\cdots \\ M_n &= F_{II}(\gamma)_n a W \end{aligned}\right\} \quad \ldots \quad (2)$$

Fig. 7 (1). — Coefficient of depression $F_I(\gamma)$.



In the above formulæ, $F_I(\gamma)_n$ and $F_{II}(\gamma)_n$ are the functions of γ, as shown in Table 4 and Figure 7, and a the spacing of sleepers.

$$\gamma = \frac{B}{D}$$

$$B = \frac{6\, E_0\, J_0}{a^3}$$

where

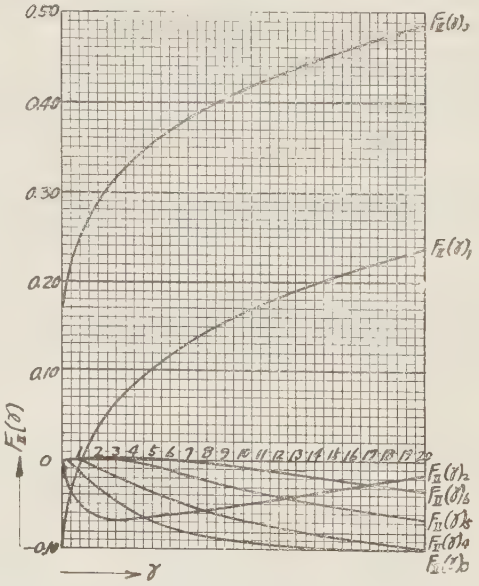
E_0 = modulus of elasticity of rail steel,

J_0 = moment of inertia of rail section,

D = rail pressure required for causing unit depression of sleeper.

When the wheel load is applied directly upon a sleeper, the rail pressure and the bending moment can be calculated by the following formulæ. The values of $f_I(\gamma)_n$ and $f_{II}(\gamma)_n$ may be found in Table 5 and Figure 8.

Fig. 7 (2). — Coefficient of bending moment $F_{II}(\gamma)$.



$$\left.\begin{aligned} P_1 &= f_I(\gamma)_1 W \\ P_2 &= f_I(\gamma)_2 W \\ &\cdots\cdots\cdots \\ P_n &= f_I(\gamma)_n W \end{aligned}\right\} \quad \ldots \quad (3)$$

$$\left.\begin{aligned} M_1 &= f_{II}(\gamma)_1 a W \\ M_2 &= f_{II}(\gamma)_2 a W \\ &\cdots\cdots\cdots\cdots \\ M_n &= f_{II}(\gamma)_n a W \end{aligned}\right\} \quad \ldots \quad (4)$$

The influence lines of the bending moment of the rail at the middle point of

TABLE 4.

$F_{I\,n}$ / γ	$F_{I\,1}$	$F_{I\,2}$	$F_{I\,3}$	$F_{I\,4}$	$F_{I\,5}$	$F_{I\,6}$	$F_{I\,7}$	$F_{I\,8}$	$F_{I\,9}$	$F_{I\,10}$
0	0.600481	−0.127405	0.034138	−0.009147	0.002451	−0.000657	0.000176	−0.000047	0.000012	−0.000002
0.1	0.560727	−0.057553	−0.004929	0.001913	−0.000140	−0.000024	0.000006	−0.000000	−0.000000	0.000000
0.5	0.485651	0.048962	−0.028846	−0.007513	0.001086	0.000697	0.000016	−0.000049	−0.000008	0.000004
1	0.441089	0.096411	0.019870	−0.016521	−0.002727	0.001007	0.000600	0.000066	−0.000048	−0.000017
2	0.393468	0.134191	0.002004	−0.019973	−0.009741	0.001484	0.000823	0.000631	0.000169	−0.000088
3	0.365572	0.150174	0.018368	−0.017404	−0.013445	−0.004497	−0.000073	0.000814	0.000479	0.000012
4	0.346023	0.158689	0.030571	−0.013372	−0.015076	−0.006983	−0.001368	0.000588	0.000672	0.000256
5	0.331133	0.163708	0.039986	−0.009100	−0.015525	−0.008875	−0.002724	0.000108	0.000728	0.000561
6	0.319186	0.166827	0.047483	−0.004969	−0.015284	−0.010269	−0.004004	−0.000506	0.000671	0.000865
7	0.309260	0.168809	0.053604	−0.001098	−0.014632	−0.011271	−0.005159	−0.001176	0.000528	0.001135
8	0.300803	0.170064	0.058701	0.002486	−0.013733	−0.011966	−0.006178	−0.001856	0.000325	0.001354
9	0.293457	0.170833	0.063015	0.005791	−0.012685	−0.012424	−0.007063	−0.002521	0.000080	0.001517
10	0.286981	0.171264	0.066714	0.008838	−0.011552	−0.012695	−0.007824	−0.003156	−0.000194	0.001624
11	0.281203	0.171456	0.069920	0.011650	−0.010374	−0.012818	−0.008473	−0.003754	−0.000488	0.001678
12	0.275994	0.171472	0.072726	0.014251	−0.009176	−0.012823	−0.009022	−0.004311	−0.000793	0.001682
13	0.271261	0.171360	0.075200	0.016663	−0.007976	−0.012734	−0.009482	−0.004827	−0.001106	0.001641
14	0.266928	0.171151	0.077398	0.018905	−0.006785	−0.012570	−0.009865	−0.005302	−0.001421	0.001561
15	0.262938	0.170869	0.079362	0.020994	−0.005611	−0.012344	−0.010177	−0.005739	−0.001737	0.001445
16	0.259243	0.170532	0.081126	0.022947	0.004458	−0.012068	−0.010430	−0.006140	−0.002051	0.001299
17	0.255807	0.170154	0.082718	0.024775	−0.003331	−0.011753	−0.010628	−0.006506	−0.002362	0.001126
18	0.252597	0.169744	0.084161	0.026492	−0.002230	−0.011405	−0.010780	−0.006841	−0.002668	0.000930
19	0.249588	0.169310	0.085475	0.028107	−0.001157	−0.011032	−0.010890	−0.007147	−0.002968	0.000714
20	0.246757	0.168859	0.086674	0.029629	−0.000111	−0.010637	−0.010963	−0.007425	−0.003263	0.000480

$F_{II\,n}$ / γ	$F_{II\,0}$	$F_{II\,1}$	$F_{II\,2}$	$F_{II\,3}$	$F_{II\,4}$	$F_{II\,5}$	$F_{II\,6}$	$F_{II\,7}$	$F_{II\,8}$	$F_{II\,9}$	$F_{II\,10}$
0	0.170753	−0.079247	0.021234	−0.005690	0.001525	−0.000408	0.000109	−0.000029	0.000008	−0.000002	−0.000000
0.1	0.187684	−0.062316	−0.001590	0.001585	−0.000171	−0.000013	0.000005	−0.000000	−0.000000	0.000000	0.000000
0.5	0.226282	−0.023718	−0.038067	−0.003454	0.002313	0.000568	−0.000092	−0.000054	−0.000001	0.000004	0.000000
1	0.254766	0.004766	−0.054135	−0.016626	0.001014	0.002132	0.000523	−0.000078	−0.000080	−0.000016	0.000001
2	0.291697	0.041697	−0.064768	−0.037077	−0.007410	0.002277	0.002223	0.000688	0.000023	−0.000101	−0.000008
3	0.317569	0.067569	−0.066859	−0.051113	−0.016999	−0.000289	0.002985	0.001753	0.000451	−0.000030	−0.000026
4	0.338017	0.088017	−0.065960	−0.061248	−0.023965	−0.004055	0.002779	0.002630	0.001118	0.000202	−0.000035
5	0.355139	0.105139	−0.063728	−0.068887	−0.034061	0.008334	0.001867	0.003194	0.001801	0.000522	−0.000026
6	0.370000	0.120000	−0.060814	−0.074800	−0.041304	−0.012776	0.000467	0.003441	0.002410	0.000873	0.000006
7	0.383208	0.133208	−0.057531	−0.079462	−0.047788	0.017212	−0.001269	0.003401	0.002904	0.001220	0.000058
8	0.394888	0.144888	−0.054050	−0.083183	−0.053612	−0.021556	−0.003234	0.003115	0.003268	0.001541	0.000129
9	0.406075	0.156075	−0.050467	−0.086175	−0.058867	−0.025767	−0.005355	0.002619	0.003502	0.001826	0.000216
10	0.416178	0.166178	−0.046840	−0.088592	−0.063628	−0.029825	−0.007581	0.001949	0.003613	0.002069	0.000314
11	0.425588	0.175588	−0.043208	−0.090546	−0.067960	−0.033725	−0.009873	0.001133	0.003611	0.002269	0.000422
12	0.434411	0.184411	−0.039592	−0.092120	0.071919	−0.037468	−0.012206	0.000195	0.003506	0.002426	0.000536
13	0.442726	0.192726	−0.036010	−0.093382	0.075550	−0.041058	−0.014560	−0.000844	0.003309	0.002543	0.000654
14	0.450597	0.200597	−0.032471	−0.094383	−0.078893	0.044503	−0.016921	−0.001965	0.003031	0.002620	0.000774
15	0.458075	0.208075	−0.028982	−0.095163	−0.081979	−0.047808	−0.019276	−0.003155	0.002681	0.002662	0.000894
16	0.465203	0.215203	−0.025547	−0.095757	−0.084838	−0.050982	0.021619	−0.004401	0.002267	0.002669	0.001014
17	0.472025	0.222025	−0.022169	−0.096192	−0.087494	−0.054033	−0.023943	−0.005693	0.001797	0.002646	0.001131
18	0.478543	0.228543	−0.018849	−0.096489	−0.089966	0.056967	0.026144	−0.007022	0.001277	0.002594	0.001244
19	0.484812	0.234812	−0.015588	−0.096669	−0.092274	−0.059791	−0.028517	−0.008380	−0.000715	0.002515	0.001354
20	0.490842	0.240842	−0.012386	−0.096747	−0.094433	−0.062512	−0.030761	−0.009760	0.000116	0.002412	0.001459

F_{In} / γ	$F_{I\,1}$	$F_{I\,2}$	$F_{I\,3}$	$F_{I\,4}$	$F_{I\,5}$	$F_{I\,6}$	$F_{I\,7}$	$F_{I\,8}$	$F_{I\,9}$	$F_{I\,10}$
0	1	0	0	0	0	0	0	0	0	0
0.1	0.842462	0.109369	−0.032831	0.001843	0.000487	−0.000104	0.000003	0.000002	−0.000000	0.000000
0.5	0.635866	0.217072	−0.016918	−0.018182	−0.001241	0.001160	0.000249	−0.000051	−0.000026	0.000004
1	0.544422	0.245024	0.012961	−0.023112	−0.008301	0.000075	0.000936	0.000271	−0.000023	−0.000042
2	0.461800	0.256017	0.048857	−0.016849	−0.015570	−0.004722	0.000206	0.000851	0.000372	−0.000062
3	0.418428	0.255470	0.069157	−0.007774	−0.017363	−0.008548	−0.001677	0.000645	0.000688	0.000188
4	0.389902	0.252517	0.082281	0.000552	−0.016863	−0.011062	−0.003653	−0.000050	0.000760	0.000567
5	0.369030	0.248994	0.091478	0.007775	−0.015360	−0.012615	−0.005419	−0.000956	0.000638	0.000950
6	0.352764	0.245430	0.098272	0.014004	0.013415	−0.013500	−0.006912	−0.001919	0.000384	0.001274
7	0.339548	0.241998	0.103479	0.019403	0.011292	−0.013923	−0.008141	−0.002861	0.000049	0.001514
8	0.328486	0.238752	0.107580	0.024121	−0.009124	−0.014020	−0.009136	−0.003746	−0.000336	0.001666
9	0.319022	0.235701	0.110877	0.028277	0.006979	−0.013884	−0.009029	−0.004557	−0.000748	0.001731
10	0.310782	0.232839	0.113570	0.031967	−0.004891	−0.013578	−0.010552	−0.005292	−0.001174	0.001720
11	0.303506	0.230151	0.115801	0.035266	−0.002878	−0.013150	−0.011030	−0.005952	−0.001603	0.001642
12	0.297008	0.227625	0.117666	0.038235	0.000947	−0.012632	−0.011386	−0.006540	−0.002030	0.001505
13	0.291150	0.255244	0.119241	0.040923	0.000900	−0.012048	−0.011640	−0.007063	−0.002451	0.001319
14	0.285828	0.222996	0.120579	0.043367	0.002665	−0.011416	−0.011807	−0.007526	−0.002862	0.001090
15	0.280958	0.220868	0.121723	0.045601	0.004350	−0.010750	−0.011901	−0.007934	0.003263	0.000827
16	0.276478	0.218850	0.122706	0.047652	0.005959	−0.010061	−0.011933	−0.008294	−0.003652	0.000535
17	0.272330	0.216932	0.123552	0.049542	0.007496	−0.009355	−0.011912	−0.008610	−0.004029	0.000219
18	0.268476	0.215106	0.124285	0.051289	0.008966	−0.008641	−0.011847	−0.008887	0.004393	−0.000117
19	0.264878	0.213363	0.124926	0.052910	0.010371	−0.007921	−0.011742	−0.009128	−0.004744	−0.000468
20	0.261510	0.211698	0.125471	0.054418	0.011717	−0.007201	−0.011606	0.009338	−0.005083	−0.000831

F_{IIn} / γ	$F_{II\,1}$	$F_{II\,2}$	$F_{II\,3}$	$F_{II\,4}$	$F_{I\,5}$	$F_{I\,6}$	$F_{II\,7}$	$F_{II\,8}$	$F_{II\,9}$	$F_{II\,10}$
0	0	0	0	0	0	0	0	0	0	0
0.1	0.050693	−0.028077	0.002524	0.000293	−0.000094	0.000006	0.000001	−0.000000	0.000000	0.000000
0.5	0.130488	0.051570	−0.016574	0.001513	0.001419	0.000083	−0.000092	−0.000018	0.000004	0.000000
1	0.175730	−0.052060	0.034825	−0.004628	0.002456	0.001240	0.000099	−0.000107	0.000042	0.000000
2	0.226875	−0.042225	−0.055309	0.019535	−0.000609	0.002745	0.001378	0.000218	−0.000087	−0.000015
3	0.259855	−0.030931	−0.066248	−0.032406	−0.006339	0.002365	0.002521	0.001003	0.000138	−0.000031
4	0.284839	−0.020210	0.072742	0.042993	−0.012692	0.000746	0.003121	0.001847	0.000529	−0.000025
5	0.305232	−0.010254	−0.076745	−0.051758	0.018996	−0.001594	0.003193	0.002560	0.000968	0.000011
6	0.322614	−0.001004	−0.079192	−0.059108	−0.025019	−0.004345	0.002825	0.003074	0.001387	0.000076
7	0.337854	0.007628	−0.080599	−0.065346	−0.030689	−0.007324	0.002108	0.003378	0.001754	0.000163
8	0.351486	0.015728	−0.081276	−0.070698	0.035997	−0.010423	0.001116	0.003483	0.002055	0.000269
9	0.363847	0.023359	0.081426	−0.075331	−0.040958	0.013569	−0.000088	0.003413	0.002287	0.000389
10	0.375193	0.030585	0.081181	−0.079373	0.045597	−0.016722	−0.001459	0.003185	0.002451	0.000516
11	0.385695	0.037449	−0.080640	−0.082925	−0.049943	−0.019854	−0.002959	0.002823	0.002551	0.000649
12	0.395485	0.043992	−0.079871	−0.086063	0.054020	−0.022945	−0.004557	0.002347	0.002593	0.000782
13	0.404664	0.050244	−0.078926	−0.088850	−0.057854	0.025985	−0.006229	0.001772	0.002581	0.000915
14	0.413313	0.056234	−0.077843	0.091336	−0.061468	−0.028966	−0.007958	0.001115	0.002521	0.001045
15	0.421496	0.061983	−0.076654	−0.093563	−0.064880	−0.031885	−0.009727	0.000389	0.002418	0.001169
16	0.429266	0.067514	−0.075380	−0.095565	−0.068108	−0.034737	−0.011524	−0.000397	0.002276	0.001288
17	0.436665	0.072841	−0.074042	−0.097369	−0.071169	−0.037523	−0.013340	−0.001231	0.002100	0.001399
18	0.443730	0.077981	−0.072653	−0.099000	−0.074076	−0.040242	−0.015165	−0.002107	0.001894	0.001503
19	0.450494	0.082947	0.071225	−0.100478	−0.076841	−0.042896	−0.016995	−0.003016	0.001659	0.001598
20	0.456980	0.087751	−0.069769	−0.101819	−0.079476	−0.045484	−0.018822	−0.003954	0.001399	0.001684

the sleeper spacing, and the rail pressure on a sleeper calculated by the formulæ (1) to (4) are shown in Figures 9 and 10.

Fig. 8 (1). — Coefficient of depression.

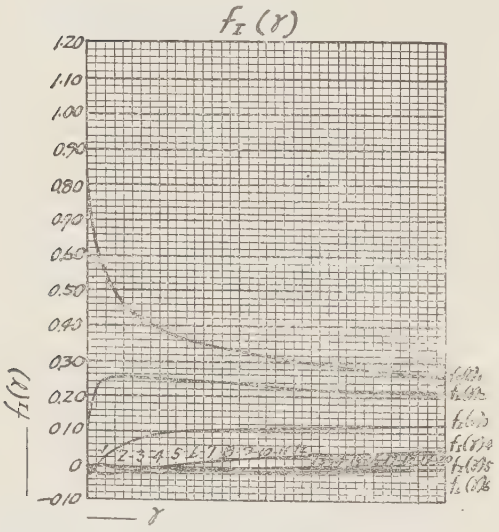


Fig. 8 (2). — Coefficient of bending moment.

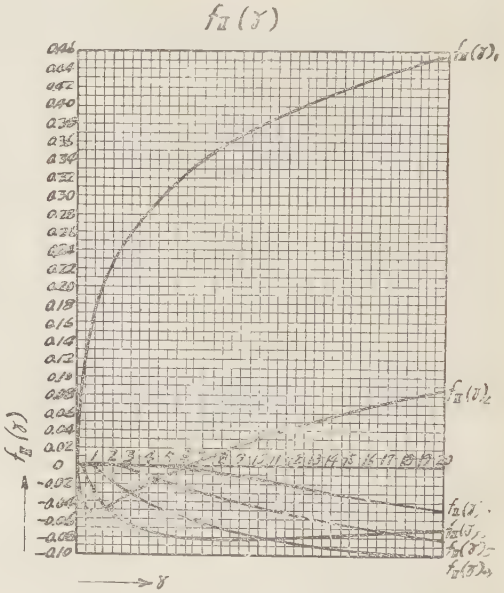


Fig. 9. — Influence line of bending moment.

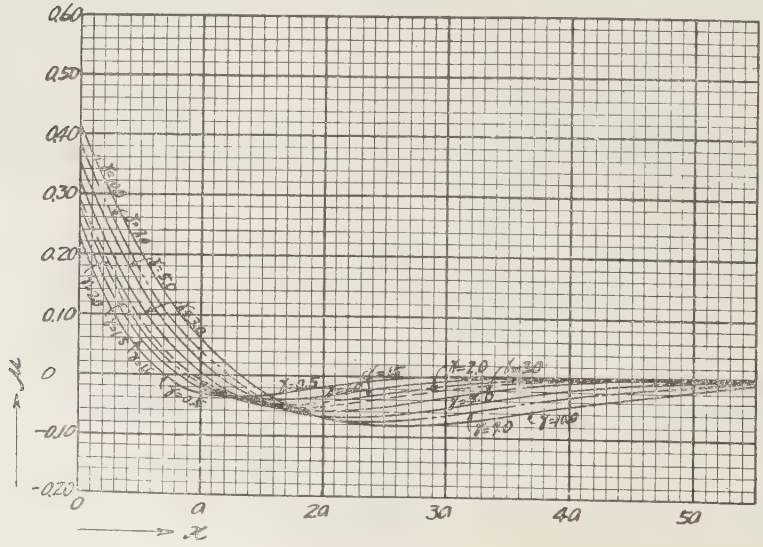
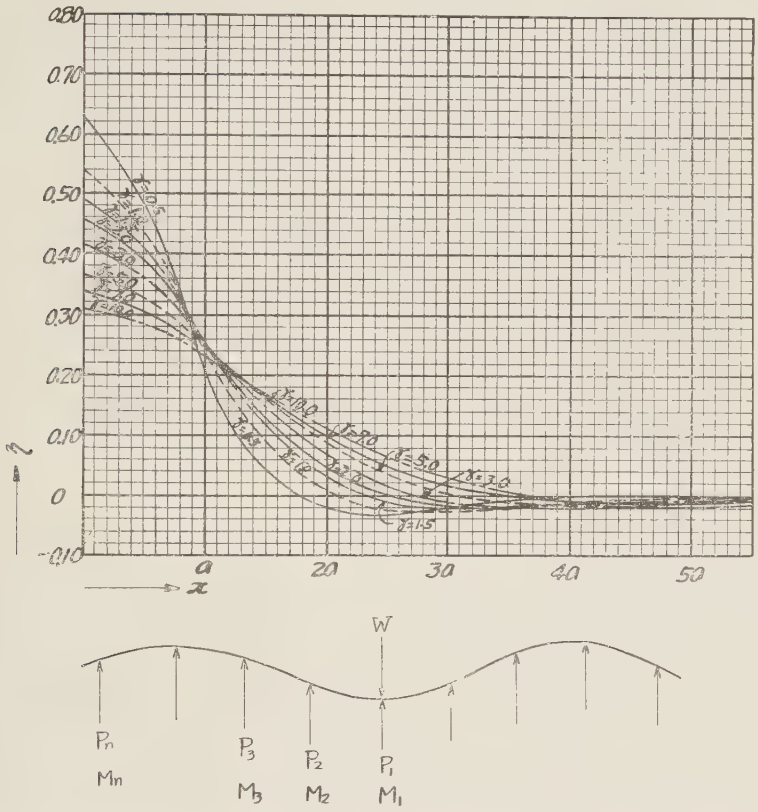


Fig. 10. — Influence line of rail pressure.



The bending moment of rail, and rail pressure which a wheel load W applied at a distance from the section under consideration develops in that section are as follows :

$$\left.\begin{aligned} M &= \mu\, a\, W \\ P &= \eta_1\, W \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad , \quad (5)$$

The stresses developed by a series of loads applied at a certain point are expressed by the following formulæ :

$$\left.\begin{aligned} M &= \Sigma\, \mu\, a\, W \\ P &= \Sigma\, \eta_1\, W \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (6)$$

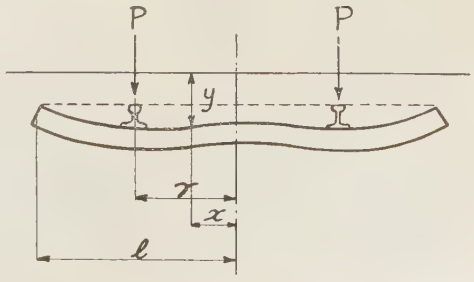
b) **Stresses in sleepers.**

If p is the pressure put upon the unit surface area of the ballast, and y its corresponding depression as shown in Figure 11, the relation

$$p = c\, y \quad . \quad . \quad . \quad . \quad . \quad (7)$$

is always proved, in which c is the

Fig. 11.



ballast coefficient. The value of c is 5 kgr./cm³ for a soft roadbed, and 13 kgr./cm³ for a good one.

When the width of sleeper is b, the moment of inertia of its section J, modulus of elasticity of sleeper E,

$$EJ \frac{d^4 y}{d x^4} = - b p = - b c y \quad . \quad (8)$$

$$\text{or} \quad \frac{d^4 y}{d x^4} + 4 K^4 y = 0 \quad . \quad . \quad (9)$$

where

$$K = \sqrt[4]{\frac{c b}{4 EJ}}$$

From (9)

$$y = (A_1 e^{-\varphi} + A_2 e^{\varphi}) \cos \varphi + (B_1 e^{-\varphi} + B_2 e^{-\varphi}) \sin \varphi \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

where

$$\varphi = K x.$$

A_1, A_2, B_1 and B_2 are constants which are determined by boundary conditions. The bending moment M and shear Q of a sleeper are expressed as follows :

$$\left.\begin{aligned} M &= - EJ \frac{d^2 y}{d x^2} \\ Q &= - EJ \frac{d^3 y}{d x^3} \end{aligned}\right\} \quad . \quad . \quad (11)$$

In the case of ordinary sleepers the maximum value of p, M and Q occurs in the section directly under the rail. If these are represented by p_r, M_r and Q_r respectively,

$$\left.\begin{aligned} p_r &= \frac{K P}{b} [\eta_\rho] \\ M_r &= \frac{P}{2 K} [\mu_\rho] \\ Q_r &= \frac{P}{2} [\mu'_\rho] \end{aligned}\right\} \quad . \quad . \quad . \quad (12)$$

where $[\eta_\rho]$, $[\mu_\rho]$ and $[\mu'_\rho]$ are the functions of c, k, the length of sleeper and the gauge of track. In general cases, the formulæ have already been solved by Dr. Zimmermann.

c) Pressure on the roadbed.

The magnitude of the vertical component of the rail pressure, distributed on the roadbed through the ballast, varies according to the size of sleeper and depth of ballast concerned. When the pressure varies along the length of a sleeper as shown in Figure 11, the vertical component of the roadbed pressure at any point directly under the sleeper is expressed by the following formula :

$$p_0 = \frac{b K^2}{\pi} \int_{-a}^{2l-a} p_x \, e^{-K^2 x^2} \, dx \quad . \quad (13)$$

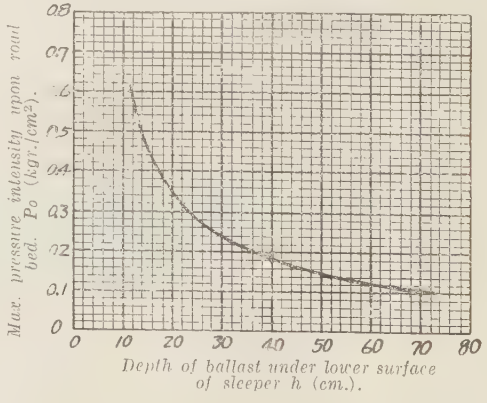
where

b = width of sleeper,
$2l$ = length of sleeper,
K = function of depth of ballast h, when $h > 10$ cm.,

$$K = \frac{1}{0.7\, h + 2.3} (h \text{ in cm.}).$$

The maximum intensity of roadbed pressure occurs in the roadbed directly under the rail, when the depth of ballast is relatively small, but as it increases, the maximum pressure intensity shifts towards the track centre. The calculated maximum pressure intensity in roadbed of track with 1.067-metre (3′ 6″) gauge, 20 cm. × 14 cm. × 213 cm. (8″ × 5 1/2″

Fig. 12. — Maximum pressure intensity upon roadbed.



$\times$ 7′ 0″) sleepers and C = 5 kgr./cm³, is shown in Figure 12. The value of p_0 given in Figure 12 has been calculated for a rail pressure of 1 metric ton. The maximum compression of roadbed for a rail pressure P tons is as follows :

$$p = p_0 \, P \quad . \quad . \quad . \quad . \quad (14)$$

d) **Impact.**

The dynamic augment of the track stresses due to the increase of the operating speed varies with the design of the counterbalance of driving wheels, the centre of gravity and the weight of the non-sprung parts of the vehicle. According to the result of investigations, steam locomotives give a greater value of impact for the vertical bending stress, while electric locomotives afford a comparatively larger value of the lateral bending stress in high-speed operation.

The dynamic augments for the bending stress of the rail and the pressure on rail supports do not always agree; generally speaking the former is larger than the latter. After a series of experiments with various types of locomotives, it has been proved that the dynamic augments of track stresses given by driving wheels can be expressed by the following formulæ :

$$\left.\begin{array}{lll} \text{Dynamic augment of the bending stress in rail} & . \; . & i = \dfrac{1.0}{100} \, V \\ \text{,} & & \\ \text{Dynamic augment of the rail pressure} & . \; . \; . \; . & i = \dfrac{0.6}{100} \, V \end{array}\right\} \quad . \quad (15)$$

where V = operating speed in kilometres per hour.

e) **Lateral bending stress in rail.**

Stresses in rail due to lateral bending differ to a great extent according to the difference in design of rolling stock. The ratio of the lateral bending stress to the vertical bending stress is shown in Table 6. The mean value of this ratio for the driving wheels amounts to about 25 % on the straight, and about 45 %

TABLE 6. — **Ratio of the lateral bending stress to the vertical bending stress in the rail foot.**

Track.	Rail.	Locomotive.	Mean value for driving wheel.					Maximum value for driving wheel.				
			0	20	40	60	80	0	20	40	60	80
Straight.		Steam.	0.192	0.194	0.198	0.203	0.209	0.216	0.213	0.219	0.222	0.241
		Electric.	0.115	0.129	0 155	0 173	0.193	0.139	0.157	0.184	0.208	0.234
R = 800 m. curve.	Outer.	Steam.	0.193	0.187	0.175	0.154	—	0.288	0.269	0.240	0.207	—
		Electric.	—		—	—	—	—	—	—	—	—
	Inner.	Steam.	0 273	0.266	0.286	0.294	—	0.342	0.336	0.351	0 361	—
		Electric.	—	—	—	—	—	—	—	—	—	—
R = 600 m. curve.	Outer.	Steam.	0.281	0.258	0.257	0.275	0.281	0.363	0.333	0.329	0.340	0.341
		Electric.	0.139	0.135	0.151	0 191	0.219	0.272	0.252	0.247	0.250	0.265
	Inner.	Steam.	0.404	0.364	0.317	0.269	0.226	0.471	0.423	0.371	0.318	0.277
		Electric.	0.272	0 249	0.218	0.183	0.148	0.370	0.342	0.305	0.266	0.209
R = 400 m. curve.	Outer.	Steam.	0.227	0.261	0.262	0.250	0.246	0.299	0.322	0.330	0 330	0 334
		Electric.	0.172	0.198	0.221	0.234	0.254	0.300	0.331	0.352	0.348	0.341
	Inner.	Steam.	0.324	0.358	0.374	0.365	0.373	0.411	0.424	0.443	0.443	0.429
		Electric.	0.287	0.297	0.306	0.319	0.326	0.410	0.429	0.433	0.439	0.441

on curved sections. Generally this ratio is larger on the inner rail than on the outer rail when the speed is lower than the equivalent speed for the superelevation, and is the reverse when the speed is higher than the equivalent speed. On a curve with a radius less than 400 m., the lateral bending stress in the inner rail is generally greater than that in the outer rail.

f) **Allowable stresses in track materials.**

According to the specification for rails supplied to the Japanese Government Rys., the tensile strength of rail steel is specified as 65 kgr./mm² (41.3 Engl. t. per sq. in.) or over. However rails rolled according to the old specification are still in service; Their tensile strength is 55 kgr./mm² (34.9 Engl. t. per sq. in.) and the endurance limit may be taken as 27.5 kgr./mm² (17.45 Engl. t. per sq. in.), which is the allowable limit of stress for rail. Besides the vertical bending stress, if one takes into account the lateral bending stress of the rail, which is 25 % of the former, and the 10 % increase of stress, due to wear of the rail section, these rails permit only 20 kgr./mm² (12.7 Engl. t. per sq. in.) for the vertical bending stress.

The allowable stresses for other track materials are as follows :

Bending stress of sleepers . .	100-120	kgr./cm²	(1 422-1 710 lb./sq. in.),
Bearing of sleepers	20- 25	»	(285-356 lb./sq. in.),
Roadbed pressure	2.3	»	(32.7 lb./sq. in.),

and the operating speed is restricted so that the sum of the static stress and the impact due to the speed does at no time exceed the allowable stresses of the materials.

* * *

CHAPTER III.

Construction of track to carry heavy loads at high speeds. (Table 7.)

1. The gauge.

(I) Gauge in the straight track;

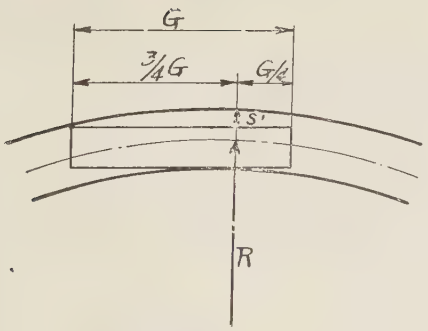
(I) Rules for widening the gauge on curves;

(III) Rules for reducing the gauge widening on curves.

The gauge is generally represented by the minimum distance between the inner sides of both rails measured within 16 to 19 mm. (5/8″ to 3/4″) below the plane of the top of the rail heads. Most Railway Administrations allow slight variations from the correct gauge, due to train operation and do not require methodical adjustment of such variations. On curved track such allowance may be larger than on the straight track, but at the frog of a turnout the incorrect gauge is to be avoided, for fear of derailment.

The practice of Railway Administrations with regard to the gauge widening on curves varies a great deal. Some Railways find no necessity whatever for widening the gauge, but try to limit the width as much as conditions permit, as excessive widening favours nosing of locomotives. But the gauge on the sharp curves should be more or less widened to permit locomotives with a long rigid wheel base to run smoothly over them.

A series of experiments made by the Japanese Government Railways has shown that the centre of rotation of the frame of vehicles running through a curve is situated at the inner wheel about 3/4 the distance from the front end of the wheel base. In this case the ne-



cessary gauge widening to ensure smooth running of the rolling stock is given by:

$$(3/4\ G)^2 = \left(2R - \frac{S'}{1\ 000}\right)\frac{S'}{1\ 000},$$

wherein

G = the maximum rigid wheel base, in metres.
R = radius of curve, in metres,
S' = widening required, in millimetres.

Substituting 4.60 m. (15′ 1 1/8″) for G,

$$S' = \frac{5\ 951}{R} = \frac{6\ 000}{R}.$$

There is, however, a play of 5 mm. (3/16″) between the flange of the wheel and the rail, which can be eliminated if the gauge is properly widened. Then the formula for the calculation of the gauge widening becomes :

$$S = \frac{6\ 000}{R} - 5.$$

The amount of widening given by this formula exceeds 30 mm. for the curve of a radius less than 170 m. To prevent the tyre leaving the rail head, the widening is limited to a maximum of 30 mm. (1 3/16″) on sharp curves.

The Reading Co., the Baltimore and Ohio, and the Chicago, Burlington and Quincy Railroads do not widen the gauge on curves flatter than 5° (R = 349 m.); the New York, Chicago and St. Louis, the Atlantic Coast Line, the Atchison Topeka and Santa Fe, and the Canadian Pacific Railways widen the gauge from 6° (R = 291 m.); the Northern Pacific, the Norfolk and Western, the Delaware and Hudson, the Illinois Central, the New York Central and the Missouri Pacific widen the gauge of every curve sharper than 8° (R = 218 m.); the Chesapeake and Ohio and the Chicago Rock Island and Pacific from 10° (R = 175 m.). On the other hand, the Japanese Government Rys commence the widening as from 800 m. radius, the Chosen Government Rys. 1 000 m., the Great Indian Peninsula Railway 1 706 m., the Ceylon Government Ry. 1 600 m., and the New Zealand Government Rys. 700 m. respectively.

The maximum amount of widening resorted to to prevent derailment is the 30 mm. (1 3/16″) used on the Japanese Government Rys. It is 19 mm. (3/4″), on the Northern Pacific, the Chesapeake and Ohio, the Atlantic Coast Line, the Chicago Rock Island and Pacific, the New York Central Lines, the Missouri Pacific, the London and North Eastern, the Canadian Pacific, and the Central Cordoba Railways; 20 mm. on the Entre Rios Railway; 15 mm. (5/8″) on the Ceylon Government Ry. (5′ 6″ gauge), and the Reading Co.; 12 mm. (1/2″) on the Baltimore and Ohio, the Norfolk and Western, the Illinois Central, the Pennsylvania, the New Zealand Government, and the Nigerian Rys.; and 11 mm. (7/16″) on the Chosen Government Rys. As has been mentioned previously, there is a tendency to widen the gauge used for high-speed operation as little as possible.

When there is a transition curve, the widening of the gauge is usually reduced along its whole length, and when there is none, the widening has to keep pace with the reduction in superelevation. If the curve also has no superelevation, the widening is reduced within a certain

TABLE 7. — Constr

RAILWAYS.	1			2
	Gauge.			
	Normal.	Widening of gauge on curves.	Length of run-off of the widened gauge.	Maximum rad of curves.
Japan and China.				
Japanese Government	1.067 m.	$\left(\frac{6\,000}{R} - 5\right)$ mm. (R in metres.)	Whole length of the transition curve if any, and in other cases 5 m. from the end of circle.	Important trunk line } 40 Ordinary trunk line } 30
Chosen Government-General	1.435 m.	400 — 500 m. 11 mm. 500 — 600 m. 7 » 600 — 700 m. 4 » 700 — 800 m. 3 » 800 — 1 000 m. 2 »	Keep pace with the run-off of superelevation.	400 m.
Chinese Rys.	1.435 m.	...	...	230 m.
Great Britain, Dominions and Colonies.				
London, Midland and Scottish	1.435 m.	201 m. — 141 m. (*10 ch.* — 7 *ch.*) 6 mm. (*1/4''*). Widening on curves sharper than 141 m. (7 ch.) in radius is decided by the location.	...	131 m. (*6 1/2 ch.*
London and North Eastern	1.435 m.	Over 141 m. (*7 ch.*) 0 mm. 141 m. (*7 ch.*) 3 mm. (1/8''). 121 m. (*6 ch.*) 6 mm. (1/4''). 101 m. (*5 ch.*) 10 mm. (3/8''). 90 m. (*4 1/2 ch.*) 13 mm (1/2''). 80 m. (*4 ch.*) and under 19 mm. (3/4'').	...	603 — 804 (*30 ch.* — *40*
Great Western	1.435 m.	Over 201 m. (*10 ch.*) 0 mm.	Reduced at the rate of 1/8'' in 2' 6'' (1/240) or less.	804 m. (*40*
Southern	1.435 m.	...	...	...
Great Northern	1.600 m.	...	...	201 m. (*10*
Great Southern	1.600 m.	Maximum 13 mm. (*1/2''*).	...	181 m. (*9*
Canadian National	1.435 m.	...	...	388 m. (*1*
Canadian Pacific	1.435 m.	Over 291 m. (6°) 0 mm. 291 — 194 m. (6° — 9°) 3 mm. (*1/8''*). 194 — 145 m. (9° — 12°) 6 mm. (*1/4''*). 145 — 117 m. (12° — 15°) 13 mm. (*1/2''*). Under 117 m. (15°) 19 mm. (*3/4''*).	Whole length of the transition curve if any, and in other cases 18.3 m. (*60'*) in the straight section.	...
North Western (India)	1.676 m.	$\left(\frac{D-2}{16}\right)''$ (D = degree of curve).	...	175 m. (*1*

on of track.

3	4	5	6	7
aximum gradient.	Maximum length of straight line to be inserted between reverse curves.	Whether a transition curve is inserted between compound curves or not.	Whether superelevation is decided for high-speed trains or low-speed trains.	Method of run-off of the superelevation.
10 %.	10 m.	No.	High-speed trains.	1 : 600 at least, usually 1 : 800 — 1 : 1 000.
25 %.				
10 %.	50 m.	No.	..	..
15 %.	15.2 m. (*50'*).	No.	The fastest train.	Whole length of transition curve.
1/37.	None.	Yes, when the difference of two radii amounts to 15 % or more of the larger one.	.	.
1/200.	27.4 m. (*90'*).	Yes.	Mainly for low-speed trains when they are predominant but takes into consideration the high-speed trains too.	1 : 500. Actually 1 : 617.
1/37.	12.2 m. (*40'*) if possible, and the minimum is 6.10 m. (*20'*).	Yes, when the difference of two radii amounts to 15 % or more.	Ordinary, maximum speed.	
...	...	...	..	...
1/75.	30.5 m. (*100'*).	Yes, when the difference of two radii amounts to 15 % or more.	High-speed trains.	1/720 (*1''/60'*).
1/60.	..	Yes, if possible.	.	...
1 %.	30.5 m. (*100'*).	Yes.	Standard of A. R. E. A.	Flatter than 1/1 200 (*1/2''/60'*), and 1/1 800 (*1/2''/75'*) if possible.
..	...	100' for a difference of superelevation 1" (*1 200 : 1*).	Decided so as to make the wear of rails on both sides minimum	1/720 (*1''/60'*).
1/25.	30.5 m. (*100'*).	No.	For the predominant train speed.	1/720 (*1''/60'*).

TABLE 7. — Construc

RAILWAYS.	1 — Gauge. Normal.	1 — Gauge. Widening of gauge on curves.	1 — Gauge. Length of run-off of the widened gauge.	2 — Maximum radius of curves.
Great Indian Peninsula	1.676 m.	10 mm. (3/8") for curves sharper than 518 m. (*1 7/6'*) in radius.	...	350 m. (*1 1/46'*).
East Indian	1.676 m.	$\left(\frac{D-2}{16}\right)''$ (D = degree of curve).	...	175 m. (*10°*).
Madras and Southern Mahratta	1.676 m.	$\left(\frac{D-2}{16}\right)''$ (D = degree of curve).	..	175 m. (*10°*).
Bengal Nagpur	1.676 m.	Over 499 m. (*3 1/2°*). — 0 mm. 499 — 437 m. (*3 1/2° — 4°*). — 3 mm. (*1/8"*). 437 — 250 m. (*4° — 7°*). — increased gradually.	...	269 m. (*882'*).
Burma	1.000 m.	...	..	437 m. (*1 432'*).
Ceylon Government	1.676 m.	101 — 141 m. (*5 ch. — 7 ch.*). — 16 mm. (*5/8"*). 141 — 201 m. (*7 ch. — 10 ch.*). — 13 mm. (*1/2"*). 201 — 503 m. (*10 ch. — 25 ch.*). — 10 mm. (*3/8"*). 503 — 1 608 m. (*25 ch. — 80 ch.*). — 6 mm. (*1/4"*).	.	101 m. (*5 ch.*).
New-Zealand Government	1.067 m.	301 m. (*15 ch.*). — 13 mm. (*1/2"*). 322 — 104 m. (*16 ch. — 35 ch*). — 6 mm. (*1/4"*). Over 704 m. (*35 ch.*). — 0 mm.	12.2 m. (*40'*). from the end of spiral.	301 m. (*15 ch.*).
New South Wales Government	1.435 m.	161 m. (*8 ch.*). — 10 mm. (*3/8"*). 161 — 201 m. (*8 ch. — 10 ch.*). — 6 mm. (*1/4"*). 201 — 241 m. (*10 ch. — 12 ch.*). — 3 mm. (*1/8"*). Over 241 m. (*12 ch.*). — 0 mm.	At a rate flatter than 1/960 (*1/4"/20'*).	221 m. (*11 ch.*).
Sudan Government	1.067 m.	Under 437 m. (*4°*). — 6 mm. (*1/4"*).	..	291 m. (*6°*).
Nigerian	1.067 m.	250 — 218 m. (*7° — 8°*). — 6 mm. (*1/4"*). Under 218 m. (*8°*). — 13 mm. (*1/2"*)	..	175 m. (*10°*).
U. S. A.				
New York, Chicago and St. Louis.	1.435 m.	No widening up to 6° (*291 m.*); widen 3 mm. (*1/8"*) for each 2° above 6°, with maximum amount of 19 mm. (*3/4"*).	...	Branch line : 93 m. (*306'*). Trunk line : 175 m. (*574'*).
Southern Ry. System	1.435 m.	...	...	...

ı of track. (*Contd.*)

3	4	5	6	7
ximum gradient.	Maximum length of straight line to be inserted between reverse curves.	Whether a transition curve is inserted between compound curves or not.	Whether superelevation is decided for high-speed trains or low-speed trains.	Method of run-off of the superelevation.
1/37.	122 m. (*400'*).	No, but restricts the difference of radii.	...	1/720 (*1/2''/30'*).
1/400 in the yard.	30.5 m. (*100'*).	No.	High-speed trains.	1/480 (*1''/40'*).
1/80.	Length sufficient to reduce the difference of superelevation at the rate of 1/720 (*1''/60'*).	...	...	.
1/60.	61 m. (*200'*).	No.	...	61 m. (*200'*).
1/200.	12.2 m. (*40'*).	Yes.	Mean of the allowable maximum speed and the mean speed of goods trains.	1/600.
1/44.	40.2 m. (*2 ch.*).	Yes.	Mean speed.	1/500.
1/70.	None, when sufficient spiral is given.	Yes.	Suppose the mean speed 64.4 km. (*40 miles*) per hour and the maximum superelevation is 102 mm. (*4''*).	1/600 (*1''/50'*).
1/40.	None.	No.	$E = \frac{0.06\ S^2}{R}$. E = superelevation (*inches*). R = radius of curve (*chains*) S = speed (m.p.h.) = sum of 1/2 of mean speed and 1/2 of maximum speed.	$L = \frac{16\ S \times E}{12}$ — maximum. $L = \frac{10\ S \times E}{12}$ — minimum. L = run off of superelevation (*feet*). S = speed (*miles p. h.*). E = superelevation (*inches*).
1/100.	21.9 m. (*72'*).	Yes, if possible.	Maximum speed.	582 m. — 349 m. (3° — 5°). 1/1 296. (*1/3''/36'*). Over 582 m. (3°). 1/2 592. (*1/3''/72'*).
1/80.	27.4 m. (*90'*).	No.	Allowable maximum speed.	1/960 (*1/2''/40'*).
1.57 %.	None.	Yes.	The most suitable for majority of trains.	At the rate of 37 mm. per distance covered in one second.
..	...	..	...	..

TABLE 7. — Constr

RAILWAYS.	1			2
	Gauge.			
	Normal.	Widening of gauge on curves.	Length of run-off of the widened gauge.	Maximum rad of curves.
Reading	1.435 m.	Over 349 m. (5°). 0 mm. 349 — 249 m. (5° — 7°). 3 mm. (1/8"). 249 — 194 m. (7° — 9°). 6 mm. (1/4"). 194 — 159 m. (9° — 11°). 10 mm. (3/8"). 159 — 134 m. (11° — 13°). 13 mm. (1/2"). Under 134 m. (13°). 16 mm. (5/8").	...	218 m. (716"
Northern Pacific	1.435 m.	218 — 175 m. (8° — 10°). 3 mm. (1/8"). 175 — 145 m. (10° — 12°). 6 mm. (1/4"). 145 — 125 m. (12° — 14°). 10 mm. (3/8"). 125 — 109 m. (14° — 16°). 13 mm. (1/2"). 109 — 97 m. (16° — 18°). 16 mm. (5/8"). Under 97 m. (18°). 19 mm. (3/4").	12.9 m. (39').	145 m. (12°
Atchison, Topeka and Santa Fe	1.435 m.	Over 291 m. (6°). 0 mm.	...	Mountainous districts Flat districts
Baltimore and Ohio	1.435 m.	349 — 175 m. (5° — 10°). 6 mm. (1/4"). Under 175 m. (10°). 13 mm. (1/2").	...	146 m. (47
New York, New Haven and Hartford.	1.435 m.	Standard of A. R. E. A.	..	290 m. (950
Chicago, Burlington and Quincy	1.435 m.	No widening up to 1 146' in radius. 1/8" wider for every 5° increase in curvature above that.	...	140 m. (45
Norfolk and Western	1.435 m	218 — 145 m. (8° — 12°). 6 mm. (1/4"). Under 145 m. (12°). 13 mm. (1/2").	..	218 m. (71
Delaware and Hudson Co.	1.435 m.	...	...	Main lines 1 7 Other lines 582 (3
Chesapeake and Ohio	1.435 m.	0 mm. for curves flatter than 175 m. (10°) in radius and gradual increase till 19 mm. (3/4") for curves sharper than 87 m. (20°) radius.	...	250 m. (1 1
Illinois Central	1.435 m.	Widening of gauge on curves sharper than 218 m. (8°) radius. Increase gradually from 0 mm. up to 13 mm. (1/2").	..	...
Great Northern	1.435 m.	None.	...	175 m. (10°

n of track. *(Contd.)*

3	4	5	6	7
ximum gradient.	Maximum length of straight line to be inserted between reverse curves.	Whether a transition curve is inserted between compound curves or not.	Whether superelevation is decided for high-speed trains or low-speed trains.	Method of run-off of the superelevation.
ain lines 0.3 %. her lines 0.7 %.	30.5 m. (*100'*).	Yes.	...	13 mm. per 10.06 m. (*1/2" per 33'*).
2.25 %.	...	No.	Heavy goods trains : Maximum superelevation 152 mm. (*6"*).	13 mm. per 10.06 m. (*1/2" per 33'*).
3 %. 0.6 %	152 m. (*500'*).	Yes.	High-speed trains : Maximum superelevation = 152 mm. (*6"*).	At the rate of 31 mm. per distance covered in one second.
5 mm. per 30.5 m. *1/2" per 100'*).	61 m. (*200'*).	Yes.	The fastest trains.	...
0.6 %. (*32' per mile*).	61 m. (*200'*).	Yes.	High-speed trains.	10 mm. per 945 m. (*3/8" per 31'*).
1.3 %.	152 m. (*500'*). if possible.	No.	...	. .
2.3 %.	91.4 m. (*300'*).	Yes.	...	107 m. (*350'*). Minimum : 50 m. (*165'*).
ld lines : 1.35 %.	30.5 m. (*100'*).	Yes.	Low-speed trains, and restricts the speed of passenger trains.	Whole length of transition curve.
ew lines : 0.5 %.				
0.8 %. uling gradient is etween 0.2 and 3 %.	...	Yes.	Standard of A. R. E. A.	Whole length of transition curve.
0.3 %.	...	Yes.	Decided taking into consideration the safety and riding of the high-speed trains and the effect upon low-speed trains.	13 mm. per 11.9 m. (*1/2" per 39'*).
2.2 %.	61 m. (*200'*).	Yes.	...	High-speed trains : 1/1 584 (*1/4"/33'*). Low-speed trains : 1/792 (*1/2"/33'*).

TABLE 7. — Constru

RAILWAYS.	1			2
	Gauge.			
	Normal.	Widening of gauge on curves.	Length of run-off of the widened gauge.	Maximum radiu of curves.
Atlantic Coast Line	1.435 m.	291 — 145 m. (6° — 12°). 3 mm. (1/8"). Under 145 m. (12°). 19 mm. (3/4").	...	437 m. (4°).
Florida East Coast	1.435 m.	Standard of A. R. E. A.	...	437 m. (4°).
Chicago, Rock Island and Pacific.	1.435 m.	No widening up to 10° (175 m.). Widen 1/8" (3 mm.) for each 2° above 10°, the maximum widening being 3/4" (19 mm.).	Whole length of transition curves.	873 m. (2°).
Pere Marquette	1.435 m.	...	...	581 m. (3°).
New York Central	1.435 m.	218 — 145 m. (8° — 12°). 6 mm. (1/4"). 145 — 109 m. (12° — 16°). 13 mm. (1/2"). 109 — 87 m. (16° — 20°). 19 mm. (3/4").	..	...
Pennsylvania	1.435 m.	No widening up to 13° (134 m.), and 13 mm. (1/2") over 13° (134 m.).	...	184 m. (9° 30')
Missouri Pacific	1.435 m.	No widening up to 8° (218 m.), widen 1/8" (3 mm.) for each 2° above 8°, with a maximum of 3/4" (19 mm.).	...	699 m. (2° 30')
Southern Pacific	1.435 m.	...	..	..
Delaware, Lackawanna and Western	1.435 m.	..	...	250 m. (819')
Other Countries.				
Entre Rios	1.435 m.	Under 300 m. 20 mm. 301 — 400 m. 15 mm. 401 — 450 m. 10 mm. 451 — 500 m. 5 mm.	...	234 m.
Central Cordoba	1.000 m.	100 m. 19 mm. 400 m. 5 mm.	5 mm./10 m.	200 m.
Paulista	1.600 m.	...	..	300 m.
Buenos Ayres and Pacific	1.676 m.	...	...	500 m.

n of track. *(Contd.)*

3	4	5	6	7
ıximum gradient.	Maximum length of straight line to be inserted between reverse curves.	Whether a transition curve is inserted between compound curves or not.	Whether superelevation is decided for high-speed trains or low-speed trains.	Method of run-off of the superelevation.
...	91.4 m. (*300'*).	Yes.	High-speed trains.	Whole length of transition curves.
/100 (*53'/mile*).	...	Yes, when the change of curvature is greater than 1°.	High-speed trains.	1/720 (*1''/60'*).
0.5 %.	30.5 m. (*100'*).	Yes.	Standard of A. R. E. A.	Whole length of transition curve.
0.5 %.	...	No.	Empirically decided for a certain intermediate speed.	Whole length of transition curve.
1.6 %.	...	Yes, when the change of curvature is greater than 1° 30'.	...	1/936 (*1/2''/spiral 39'*).
1.85 %.	Sufficient length to reduce the difference in superelevation.	Yes.	Decided so as to ensure comfortable riding.	Under 80.5 km./h. (*50 m.p.h.*) 1/744 (*1/2''/31'*). Over 80.5 km./h. (*50 m.p.h.*) 1/992 (*3/8''/31'*). Electrified sections: 1/1 488 (*1/4''/31'*).
ntainous districts: 0.7 %. districts: 0.3 %.	...	...	...	...
...	...	...	...	...
1.5 %.	122 m. (*400*).	Yes, when the change of curvature is greater than 1°.	High-speed trains.	Whole length of transition curves.
1/92.	Maximum truck length.	No.	$V = \frac{\sqrt{(\text{max.})^2 + (\text{min.})^2}}{2}$	1 : 600; 2/3 of the whole length in the straight section, and 1/3 in the curved section.
28 o/oo.	70 m.	...	For the speed of 50 km./h.	5 mm./10 m.
20 o/oo.	15.2 m.	Yes.	S = 0.66 V/R. S = superelevation (metres). V = speed (km./hour). R = radius of curve (metres)	2 cm./12 m.
6.66 o/oo.	...	...	...	1 cm./10 m.

length. It is 5 m. (16′ 5″) on the Japanese Government Rys., 11.889 m. (39′) on the Northern Pacific, 18.30 m. (60′) on the Canadian Pacific, and 12.2 m. (40′) on the New Zealand Government Rys. On the other hand, the Great Western Ry. reduces the widening at the rate of 1/8″ per 2′ 6″ (1 : 240), the Central Cordoba Ry. 5 mm. per 10 m. (1 : 2 000), and the New South Wales Government Rys. 1/4″ per 20′ (1 : 960).

2. The minimum radius of curves.

The speed restriction on sharp curves is generally very severe, it being necessary to make the curve as flat as possible to ensure safe operation of high-speed trains. Especially short reverse curves at the entrance or exit of yards or bridges must be flat enough to ensure smooth riding.

Generally speaking, narrow-gauge railways allow comparatively sharp curves on the main line. On the Japanese Government Rys. the minimum radius of curve is 400 m. (1 312′) on the most important main line and 300 m. (984′) on the ordinary main line. The Burma Rys. limit it to 437 m. (1 432′), the New Zealand Government Rys. and the Sudan Government Rys. to 300 m., the Central Cordoba Railway to 200 m. (656′) and the Nigerian Ry. to 175 m. (10°).

Most standard-gauge railways do not allow sharp curves in the main line, except in mountainous districts. A few Railways make the minimum radius of their main line curves larger than 500 m. (1 640′). The minimum radius of curve of the Atchison Topeka and Santa Fe Ry. is 582 m. (1 910′) except in mountain regions; the Delaware and Hudson 1 746 m. (1°) on main line and 582 m. (3°) on other lines, the Atlantic Coast Line and the Florida East Coast RR. 437 m. (1 432′), the Chicago Rock Island and Pacific Ry. 873 m. (2°), the Pere Marquette Ry. 582 m. (1 910′), and the Missouri Pacific Railroad 699 m. (2° 30′). These are the typical railways with flat curves in the United States; other railways allow a radius less than 300 m. : the Northern Pacific Ry. 145 m. (12°), the Baltimore and Ohio RR. 146 m. (478′), and the Chicago, Burlington and Quincy RR. 140 m. (459′).

In Great Britain, the London, Midland and Scottish Ry. allows a curve with a radius of 131 m. (6 1/2 chs.) as the minimum, but this is rather a rare case, other railways using comparatively flat curves. The minimum radius on the London and North Eastern Ry. is from 603 m. to 804 m. (30 to 40 chs.), on the Great Western Ry. 804 m. (40 chs.), and on the Southern Ry. 603 m. (30 chs.). On the other hand, most railways in the British Dominions and Colonies adopt very sharp curves and restrict the train speed correspondingly.

The maximum allowable speed for the minimum curve on main lines is 70 km. (43.5 miles) per hour on the Japanese Government Rys., 96.6 km. (60 miles) per hour on the Atlantic Coast Line, 88.5 km. (55 miles) per hour on the Florida East Coast RR., 24.2 km. (15 miles) per hour on the Northern Pacific Ry., and 56.3 km. (35 miles) per hour on the Baltimore and Ohio RR. respectively.

3. Maximum gradient.

The steep gradient is one of the greatest obstacles to fast train operation and, like sharp curves, is objectionable on main lines. The gradient of the track for high-speed operation should be flat; therefore some railways adopt a gradient of 0.2 % (1/500) as the steepest.

The lines of the Japanese Government Rys. run through mountainous regions, but the maximum gradient on the most important main line — also Chosen Government Rys. — is restricted to 1 %, while that on the Chinese Government Rys. is 1.5 %.

In the United States the maximum gradient of 0.21 % (2 1/2″ per 100′) is

found on the Baltimore and Ohio RR., on its important main line; 0.2 % to 0.3 % on the Chesapeake and Ohio; 0.3 % on the Illinois Central; 0.3 % in flat districts and 0.7 % in mountainous districts on the Missouri Pacific; 0.5 % on the Pere Marquette and the Delaware and Hudson, and 0.6 % on the New York, New Haven and Hartford and the Atchison Topeka and Santa Fe, excluding lines in mountainous districts are examples of flat gradients. For other railways this is generally over 1 %, the steepest gradient being 3 %.

In Great Britain the maximum gradient is 0.5 % on the London and North Eastern Railway, which is the flattest, but on other railways there exist comparatively steep gradients.

In spite of the inevitable increase in length and the corresponding high construction cost, it is important to limit the maximum gradient to 1 % for high-speed tracks, and most desirable to maintain it at less than 0.5 %.

4. Length of straight line to be inserted between reverse curves.

When trains run over a curve at a speed higher than that for which the superelevation is given, the resultant of the centrifugal force and the weight of the vehicles passes the rail level at some distance from the centre line of the track, and the bodies of vehicles are inclined outwards on their springs. In the case of reverse curves, the direction of inclination will be suddenly reversed at the point of inflection, and cause quite unpleasant riding.

To prevent such rough riding in reverse curves, a sufficient length of straight section should be inserted between the ends of reverse curves, which length must be increased in proportion to the train speed.

The Japanese Government Rys. specify the minimum length of this straight section to be 10 m. (33′) at least, the Chinese Rys. 15.20 m. (50′), the Great Western Ry. 6.10 m. (20′), the Southern Ry. 18.30 m. (60′) and the Burma Rys. 12.20 m. (40′). In Great Britain and the United States most Railway Administrations adopt 30.50 m. (100′) as the minimum length of such a straight section, and in some cases even a length of 61 m. (200′) is inserted. On the Atchison Topeka and Santa Fe and the Chicago, Burlington and Quincy, it is 152 m. (500′), and on the Great Indian Peninsula and the Delaware, Lackawanna and Western 122 m. (400′). On the other hand, the Entre Rios Ry. inserts a length of straight section equal to the maximum length of the car body, while some railways do not insert any straight section when both reverse curves are properly transitioned. Nevertheless in general cases, insertion of a proper length of straight section between the ends of transitions of reverse curve is indispensable to ensure smooth running of high-speed trains, and the length should be increased in proportion to the operating speed.

5. Transition curves at the point of compound curves.

In the United States almost all railways use a transition curve at the point of the compound curve, but a few railways transition the compound curve only when the difference between their degrees amounts to 1° to 1° 30′.

The Japanese Government Rys., the Chosen Government Rys, and the Chinese Rys. lay no such transition curve at all.

In Great Britain, its Dominions and Colonies, some Railway Administrations use a transition curve when the difference between radii amounts to 15 % of the larger one; there are also other Railways which think this unnecessary.

To ensure smooth running of high-speed trains the curve must always be superelevated taking into account the radius and the operating speed. Therefore, at the point of the compound

curve, the radius of one curve should be gradually increased or decreased to the radius of the other curve, corresponding to the height of the varying superelevation.

6. Amount of superelevation for track section where both high and low-speed trains are operated.

Undoubtedly it is most desirable that the outer rail of curved track should be superelevated in order to maintain safe running and comfortable riding of high-speed passenger trains. But in the case of a sharp curve the theoretical superelevation suitable for the high-speed train has a large value, and the low-speed goods train runs the risk of derailing on the inner side of the curve, when it runs over the same track. Moreover, when such low-speed trains are frequent, excessive superelevation causes undue wear of the inner rail and increases the cost of track maintenance. In such a case, therefore, the curve is to be superelevated to suit a certain intermediate speed that will neither prevent smooth riding nor cause undue wear of the rail.

Most railways in the United States adopt the « safe speed » as it is called by the A. R. E. A. as the allowable maximum speed on curves. The « safe speed » is that at which the resultant of the centrifugal force acting on the centre of gravity and the gravitational force comes to the outer end of the middle third of the gauge at the plane of the rail surface. No train is allowed to operate at a speed higher than « safe speed ». Moreover, the passenger train should keep its operating speed lower than the « comfortable speed » so as not to upset riding conditions. The « comfortable speed » on a curve is a speed that corresponds to the superelevation 75 mm. (3″) higher than the actual one. It is proved so far by experiments that lack of superelevation would not cause the passenger any discomfort until it amounts to 3″.

Some Railway Administrations mainly operating goods trains, provide their tracks with the superelevation best adapted to them, and restrict the speed of passenger trains running thereon within the limit of the « comfortable speed ».

The Japanese Government Rys. provide on their tracks carrying various kinds of trains at different speeds the superelevation calculated for the mean speed of trains, taking into consideration the number and importance of each kind of train, and restricting the maximum speed so that the resultant of the centrifugal and gravitational forces may pass within the end of the middle fourth of the gauge at the plane of the rail surface.

Although such cases are very rare, some Railway Companies superelevate their curves to suit the maximum allowable speed.

In conclusion, it is the general practice to adopt superelevation mainly for the high-speed train. On the special track where low-speed goods trains are predominant, the superelevation most suitable for these trains is provided and when the superelevation is insufficient for the high-speed train, the operating speed of passenger trains is restricted so as not to harm riding conditions.

7. Length of the run-off of superelevation (superelevation ramp).

When there is a transition curve the superelevation is reduced over its whole length. But when the length of the transition curve is not sufficient, the superelevation ramp is extended into the straight section.

It is most reasonable that the length of the superelevation run-off should be increased in proportion to the operating speed. The angular velocity of the rolling motion of vehicles at the

beginning or end of a curve is proportional to the operating speed of the train if the length of the superelevation run-off is constant, and the angular velocity of the rolling motion of too high value causes very unpleasant riding to passengers, especially in the case of reverse curves. Every railway specifies that the length of superelevation run-off should be 500 times the amount of superelevation, at least on tracks for high-speed operation.

The Japanese Government Rys. make the length of run-off 300 to 450 times as long as the superelevation height on the secondary lines, and on main line over 600 times the superelevation. In the most important sections, however, the superelevation is run off in a length of 1 000 times the amount of superelevation, and over.

In the United States this length is especially appreciable. Most Railways reduce superelevation at the rate of 1/2″ per 31′ or 39′, the slope of the surface of the outer rail being 1/744 or 1/936.

The Great Northern Ry. reduces the superelevation at the rate of 1/4″ per 33′, its slope being 1/1 584, and the Pennsylvania RR. at the rate of 1/4″ per 31′ or 1/1 488 on the electrified lines.

Some Railway Administrations decide the slope of the rail surface in proportion to the distance covered during one second by the train with the highest speed, in order to make the angular velocity of rolling of the vehicle at the run-off section a constant. For example, the New York, Chicago and St. Louis makes the slope of the outer rail 1.5″ per distance travelled during one second, the Atchison, Topeka and Santa Fe 1.22″, and the Illinois Central Railroad 1.25″.

The Baltimore and Ohio Railroad uses the slope of 1″ per maximum allowable number of miles per hour travelled by the train, in terms of feet. Assuming the train speed to be 60 m.p.h., the slopes of the rail surface at the run-off section of the superelevation will be 1/705, 1/865, 1/844, and 1/720 for the above Railways respectively. The Canadian National Rys. makes the slope flatter than 1/2″ per 50′, or 1/1 200, and 1/2″ per 75′, or 1/1 800 if possible.

The Sudan Government Rys. make this slope 1/3″ per 36′ or 1/1 296 for 3° to 5° curves (582 m. to 350 m. in radius), and for the curves flatter than 3°, 1/3″ per 72′ or 1/2 592. But such a slope is rather rare.

In general, for a high-speed track, the standard slope of run-off is 1/700 to 1/1 000, and if the curve is transitioned within this length, sufficiently smooth riding may be obtained.

8. Rail.

(I) Weight of rail.

The weight of rails laid in the track for high-speed operation varies from 45 kgr./m. (90 lb./yard) to 76 kgr./m. (152 lb./yard) — as shown in table 8 (I) *(see pages 544/230 to 551/237)* — according to the axle loads of locomotives and the operating speed.

The Railways in the United States where locomotives with very heavy axle loads are operated, use rails heavier than those in any other countries, such as the 152-lb. rail adopted by the Pennsylvania RR., and the 112-lb. or 130-lb. rails on other railways.

In Great Britain, its Dominions and Colonies, rails lighter than 100 lb./yard 50 kgr./m.), are used excepting the 130-lb./yard adopted by the Canadian National Rys. on its main lines, and the four main-line Railways (London and North Eastern, the London, Midland and Scottish; the Great Western and the Southern) use rails weighing 90 lb./yard (45 kgr./m.) or 100 lb./yard (50 kgr./m.). On the other railways in the Dominions and Colonies 90-lb./yard (45-kgr./m.) rails or lighter ones are used.

The value of

$$\frac{\text{weight of rail, in kgr./m.}}{\text{maximum axle load of locomotives, in tons}}$$

TABLE 8 (I). — Rai

RAILWAYS.	1						
	Rail.						
	Weight, kgr. per m. (*lb. per yard*) and sectional area, cm.² (*sq. in.*).	Standard length.	Cant of rail.	Welding.			Sectional area of a fish-pl and ratio of the sectio area of a pair of fish-pla to that of the rail.
				Method.	Length.	Joint gap.	
Japan and China.							
Japanese Government . .	50 kgr. (*100.8 lb.*). 64.35 cm² (*9.97 sq. in.*).	25 m. (*82'*).	1 : 20	. .	. .	. .	28.6 cm² (*5.64 sq. in.*) 0.89
Chosen, Government-General.	. .	...	. .	. .	. .	. .	...
Chinese Rys. . . .	43 kgr. (*86.6 lb.*).	10 m. (*32' 9''*) and 12 m. (*39' 4 1/2''*)	. .	. .	. .	. .	...
Great Britain, Dominions and Colonies.							
London, Midland and Scottish.	47.1 kgr. (*95 lb.*). 59.9 cm² (*9.284 sq. in.*).	18.288 m. (*60'*)	1 : 20	. .	. .		20.8 cm² (*3.33 sq. in.*) 0.72
London and North Eastern.	47.1 kgr. (*95 lb.*). 59.9 cm² (*9.28 sq. in.*). 49.6 kgr. (*100 lb.*). 63.1 cm² (*9.80 sq. in.*).	18.288 m. (*60'*) 27.432 m. (*90'*)	1 : 20	Tentatively adopts welding.			21.6 cm² (*3.35 sq. in.*) 0.72
Great Western . . .	46.9 kgr. (*95 lb.*). 59.9 cm² (*9.28 sq. in.*).	18.288 m. (*60'*)	1 : 20	...	. .	. .	21.7 cm² (*3.36 sq. in.*) 0.72
Southern	47.1 kgr. (*95 lb.*). 59.9 cm² (*9.28 sq. in.*). 49.6 kgr. (*100 lb.*). 63.2 cm² (*9.80 sq. in.*).	18.288 m. (*60'*)	1 : 20	Thermit (tentatively).	36.576 m (*120'*)	8 mm. (*5/16'*)	21.0 cm² (*3.26 sq. in.* 95-lb. rail : 0.70. 100-lb. rail : 0.67.
Great Northern	44.6 kgr. (*90 lb.*).	18.288 m. (*60'*)	1 : 20	...	...	.	...
Great Southern . . .	44.6 kgr. (*90 lb.*). 56.9 cm² (*8.81 sq. in.*).	13.716 m. (*45'*)	1 : 20	...	..	...	21.7 cm² (*3.36 sq. in.* 0.77
Canadian National . .	64.5 kgr. (*130 lb.*). 81.6 cm² (*12.66 sq. in.*). 49.6 kgr. (*100 lb.*). 63.4 cm² (*9.84 sq. in.*).	11.887 m. (*39'*)	'anted.	...	...	...	130-lb. rail : 39.3 cm² (*6.09 sq. in* 0.96 100-lb. rail : 29.7 cm² (*4.61 sq. in* 0.94
Canadian Pacific . . .	49.6 kgr. (*100 lb.*). 64.1 cm² (*9.95 sq. in.*).	11.887 m. (*39'*)	1 : 20	...	. .	..	30.5 cm² (*4.72 sq. in* 0.95
North Western (India) .	44.6 kgr. (*90 lb.*). 5.7 cm² (*8.83 sq. in.*).	12.802 m. (*42'*)	1 : 20	...	...	...	28.5 cm² (*4.41 sq. in* 1.00.
Great Indian Peninsula .	49.6 kgr. (*100 lb.*). 63.4 cm² (*9.82 sq. in.*).	10.972 m. (*36'*) 12.802 m. (*42'*)	1 : 20	...	. .	...	31.3 cm² (*4.85 sq. in* 0.99

d rail joints.

2

Rail joints.

eter of fish bolts and nber of bolts applied to oint.	Type of joint.	Opposite or alternate?	Width of gap.	Method of repairing battered joints, and results obtained.
25 mm. (*1*''). 4	Suspended.	Opposite.	0° C. 10 mm. (*3/8*''). 10° C. 7 mm. (*9/32*''). 20° C. 4 mm. (*5/32*''). 30° C. 0 mm.	Shims for fish-plates. Welding of rail ends tentatively (gas welding).
..	Suspended.	Opposite.	...	...
22 mm. (*7/8*''). 4	Suspended.	Opposite and alternate.	..	Shims for fish-plates. Electric arc welding tentatively.
24 mm. (*15/16*''). 4 for fish-plates 457 mm. (*18*'') long. 2 for fish-plates 229 mm. (*9*'') long.	Suspended.	Opposite and alternate.		Reforming of fish-plates.
24 mm. (*15/16*''). 4	Suspended.	Opposite.	16 mm. (*5/8*'') for 90' and 60'-rail; 13 mm. (*1/2*'') for 45'-rail.	Shims for fish-plates.
24 mm. (*15/16*'') 2 for fish-plates 229 mm. (*9*'') long.	Suspended.	Opposite.	...	Shim.
24 mm. (*15/16*''). 4	Suspended.	Opposite.	..	Use of shims, or reforming of fish-plates.
24 mm. (*15/16*''). 4	Suspended.	Opposite.	...	Reforming of fish-plates. Satisfactory.
24 mm. (*15/16*''). 2	Suspended.	Opposite.	5 mm. (*3/16*'').	Fish-plates reformed with special die (« Brinker process »).
29 mm. (*1 1/8*'). 4	Suspended.	Alternate.	Increased gradually from 0 to 9.5 mm. (*3/8*'') as the temperature decreases from 37.8° C. to 31.7° C. (from *100°* F. to *25°* F.).	Rail ends, by oxy-acetylene process. Satisfactory.
25 mm. (*1*''). 4	Suspended. or supported.	Alternate.	Increased gradually from 0 to 7.9 mm. (*5/16*'') as the temperature decreases from 37.8° C. to 31.7° C. (*100°* F. to *25°* F.).	Rail ends, by electric arc-welding. Satisfactory.
25 mm. (*1*''). 4	Suspended.	On the straight: opposite. On curves: alternate.	...	...
24 mm. (*15/16*''). 4	Suspended.	Opposite.	6 mm. (*1/4*'').	..

TABLE 8 (l). — Ra

RAILWAYS.	1						
	Rail.						
	Weight, kgr. per m. (*lb. per yard*) and sectional area, cm.² (*sq. in.*).	Standard length.	Cant of rail.	Welding.			Sectional area of a fish-p and ratio of the sect area of a pair of fish-p to that of the rail.
				Method.	Length.	Joint gap.	
East Indian	44.6 kgr. (*90 lb.*). 56.9 cm² (*8.82 sq. in.*). 57.0 kgr. (*115 lb.*). 72.6 cm² (*11.28 sq. in.*).	12.802 m. (*42'*)	1 : 20	...	...	...	90-lb. rail : 25.5 cm² (*3.95 sq. in.* 0.89 115-lb. rail : 31.8 cm² (*4.93 sq. in.* 0.87
Madras and Southern Mahratta	44.6 kgr. (*90 lb.*).	12.192 m. (*40'*)	1 : 20	...	...	...	...
Bengal Nagpur	44.6 kgr. (*90 lb.*). 57.0 cm² (*8.83 sq. in.*).	13.716 m. (*45'*)	Canted.	...	...	...	27.6 cm² (*4.27 sq. in.* 0.96
Burma Rys.	37.2 kgr. (*75 lb.*). 47.4 cm² (*7.35 sq. in.*). 29.8 kgr. (*60 lb.*). 38.1 cm² (*5.90 sq. in.*).	11.887 m. (*39'*) 10.976 m. (*36'*)	1 : 20	...	...	...	75-lb. rail : 21.0 cm² (*3.26 sq. in.* 0.89 60-lb. rail : 13.6 cm² (*2.1 sq. in.* 0.71
Ceylon Government	43.6 kgr. (*88 lb.*). 39.7 kgr. (*80 lb.*).	9.144 m. (*30'*)	Canted.	...	...	...	17.1 cm² (*2.65 sq. in*
New Zealand Government	34.7 kgr. (*70 lb.*). 44.3 cm² (*6.88 sq. in.*). 49.6 kgr. (*100 lb.*). 63.4 cm² (*9.81 sq. in.*).	12.802 m. (*42'*)	1 : 20	Thermit.	64.05 m. (*210'*)	...	70-lb. rail : 16.1 cm² (*2.50 sq. in* 0.73 100-lb. rail : 26.4 cm² (*4.09 sq. in.* 0.85
New South Wales Government	49.6 kgr. (*100 lb.*). 64.1 cm² (*9.95 sq. in.*).	13.716 m. (*45'*)	1 : 20	Thermit.	Generally 68.6 m. (*225'*) Tentatively 549 m. (*1 800'*)	...	29.9 cm² (*4.64 sq. in* 0.93
Sudan Government	37.2 kgr. (*75 lb.*). 48.5 cm² (*7.51 sq. in.*).	10.972 m. (*36'*)	1 : 20	...	...	...	17.8 cm² (*2.75 sq. in* 0.73
Nigerian Ry.	39.7 kgr. (*80 lb.*).	12.192 m. (*40'*)	1 : 20	...	...	...	17.5 cm² (*2.71 sq. in* 0.69
U. S. A.							
New York, Chicago and St. Louis	55.8 kgr. (*112.4 lb.*). 71.1 cm² (*11.02 sq. in.*).	11.887 m. (*39'*)	1 : 40	...	...	...	35.7 cm² (*5.54 sq. in* 1.01
Southern Ry. Syst.	49.6 kgr. (*100 lb.*). 64.5 kgr. (*130 lb.*).	11.887 m. (*39'*)	...	...	...	...	...
Reading Co.	64.5 kgr. (*130 lb.*). 82.0 cm² (*12.7 sq. in.*).	11.887 m. (*39'*)	1 : 20	...	...	...	53.1 cm² (*8.24 sq. in* 1.30

rail joints. (*Contd.*)

2				
Rail joints.				
er of fish bolts and ber of bolts applied to int.	Type of joint.	Opposite or alternate?	Width of gap.	Method of repairing battered joints, and results obtained.
25 mm. (*1*''). 4	Suspended.	Opposite and alternate.	...	Reforming of fish-plates. Unsatisfactory.
9 mm. (*1 1/8*''). 4				
25 mm. (*1*''). 4	Suspended.	Opposite.	6.4 mm. (*1/4*'').	...
25 mm. (*1*''). 4	Suspended.	Opposite.	6.4 mm. (*1/4*'').	..
25 mm. (*1*''). 4	Suspended.	Opposite.	...	..
22 mm. (*7/8*''). 4				
25 mm. (*1*''). 4	Suspended.	Opposite.	15.6° C. (*60° F.*) : 9.5 mm. (*12/32*''). 26.7° C. (*80° F.*) : 7.1 mm. (*9/32*'').	..
22 mm. (*7/8*''). 4	Suspended.	Opposite.	Hot days : 1.6 mm. (*1/16*''). Warm days : 6.4 mm. (*1/4*''). Cold days : 9.5 mm. (*3/8*'').	...
25 mm. (*1*''). 4				
25 mm. (*1*''). 4	Suspended.	Opposite.	...	.
22 mm. (*7/8*''). 4	Suspended.	Opposite.	Summer : 3.2 mm. (*1/8*''). Winter : 6.4 mm. (*1/4*'').	...
22 mm. (*7/8*''). 4	Suspended.	On the straight : opposite. On curves : alternate.	Maximum : 9.5 mm. (*3/8*'') for 12.192 m. rail : (*40'*).	Shims.
the shank : 24 mm. (*15/16*''). over the threads : 25 mm. (*1*''). 4	Three-tie joint.	Alternate.	9.5 mm. (*3/8*'') — 0 for — 17.8° C. (*10° F.*) to 37.8° C. (*100° F.*).	Rail ends : by building up with gas or electric arc welding. Fish-plates : by reforming. Satisfactory.
	...	Alternate.	...	...
9 mm. (*1 1/8*''). 4	At random.	Alternate.	3.2 mm. (*1/8*'').	Welding. Satisfactory.

TABLE 8 (I). —

RAILWAYS.	1						
	Rail.						
	Weight, kgr. per m. (*lb. per yard*) and sectional area, cm.² (*sq. in.*).	Standard length.	Cant of rail.	Welding.			Sectional area of a fish- and ratio of the sect area of a pair of fish-p to that of the rail.
				Method.	Length.	Joint gap.	
Northern Pacific . . .	49.6 kgr. (*100 lb.*). 64.2 cm² (*9.95 sq. in.*).	11.887 m. (*39'*)	1 : 88	...	...	..	37.6 cm² (*5.83 sq. in* 1.17
Atchison, Topeka and Santa Fe	55.5 kgr. (*112 lb.*). 71.1 cm² (*11.02 sq. in.*).	11.887 m. (*39'*)	1 : 44	...	...	...	36.6 cm² (*5.67 sq. in* 1.03
Baltimore and Ohio . .	64.9 kgr. (*131 lb.*). 83.0 cm² (*12.86 sq. in.*).	11.887 m. (*39'*)	1 : 40	...	...	...	44.2 cm² (*6.85 sq. in* 1.06
New York, New Haven and Hartford	53.0 kgr. (*107 lb.*). 55.5 kgr. (*112 lb.*). 64.5 kgr. (*130 lb.*).	11.887 m. (*39'*)	1 : 20	...	...	...	Ratio : 1.02.
Chicago, Burlington and Quincy	44.6 kgr. (*90 lb.*). 49.6 kgr. (*100 lb.*). 54.6 kgr. (*110 lb.*). 55.5 kgr. (*112 lb.*).	11.887 m. (*39'*)	1 : 40	...	...	...	112-lb. rail : 36.6 cm² (*5.67 sq .in* 1.03
Norfolk and Western . .	64.9 kgr. (*131 lb.*). 82.9 cm² (*12.86 sq. in.*).	11.887 m. (*39'*)	1 : 20	...	...	...	...
Delaware and Hudson. .	65.0 kgr. (*131 lb.*). 89.2 cm² (*12.86 sq. in.*). 64.5 kgr. (*130 lb.*). 82.0 cm² (*12.71 sq. in.*).	11.887 m. (*39'*)	1 : 40	Thermit. Electric arc.	152 m. — 2 130 m. (*500' — 6 983'*)	5.4 mm. (*1/4''*)	35.8 cm² (*5.54 sq. in* 0.86 32.7 cm² (*5.06 sq. i* 0.79
Chesapeake and Ohio . .	64.9 kgr. (*131 lb.*). 82.9 cm² (*12.86 sq. in.*).	11.887 m. (*39'*)	1 : 40	...	...	..	40.5 cm² (*6.28 sq. i* 0.98
Illinois Central .	55.5 kgr. (*112 lb.*). 71.1 cm² (*11.02 sq. in.*).	11.887 m. (*39'*)	1 : 44	...	...	...	35 cm² (*5.42 sq. in* 0.98
Great Northern . . .	54.6 kgr. (*110 lb.*). 70.1 cm² (*10.87 sq. in.*).	11.887 m. (*39'*)	Canted.	...	...	..	36.7 cm² (*5.69 sq. i* 1.05
Atlantic Coast Line .	49.6 kgr. (*100 lb.*).	11.887 m. (*39'*)	Canted.	...	...	...	...
Florida East Coast . . .	44.6 kgr. (*90 lb.*). 56.8 cm² (*8.82 sq. in.*).	11.887 m. (*39'*)	...	...	...	...	29.1 cm² (*4.50 sq. i* 1.02
Chicago, Rock Island and Pacific	55.5 kgr. (*112 lb.*). 71.1 cm² (*11.02 sq. in.*).	11.887 m. (*39'*)	1 : 44	...	...	...	...

ıd rail joints. (*Contd.*)

2				
Rail joints.				
ıeter of fish bolts and mber of bolts applied to joint.	Type of joint.	Opposite or alternate?	Width of gap.	Method of repairing battered joints, and results obtained.
ia. over the threads: 27 mm. (*1 1/16"*). 4	Suspended.	Alternate.	—17.8° C. (*10° F.*) : 6.4 mm. (*1/4"*) 23.9 — 32.3° C. (*75 — 90° F.*) : 1.6 mm. (*1/16"*).	Electric arc welding. Satisfactory.
25 mm. (*1"*). 4	...	Alternate.	—17.8° C. (*1°° F.*) : 6.4 mm. (*1/4"*) 26.7 — 37.8° C. (*8°/ — 100° F.*) : 1.6 mm. (*1/16"*).	Rail ends : by gas or electric arc welding. Fish-plates : by reforming or by the insertion of shims.
24 mm. (*15/16"*). 6	Supported.	Alternate.	...	Do.
25 mm. (*1"*) ınd 29 mm. (*1 1/8"*). 4	Suspended. Supported.	Alternate.	A. R. E. A. standard.	Gas welding.
25 mm. (*1"*). 4	Suspended. Supported.	Alternate.	18.3° C. (*65° F.*) : 0 mm. —17.8 — —9.5° C. (*10 — 15° F.*) : 4.8 mm. (*3/16"*)	Rail ends : by gas or electric arc welding. Fish-plates : by gas welding. Satisfactory.
29 mm. (*1 1/8"*). 4	Suspended.	Alternate.	26.7 — 37.8° C. (*80 — 100° F.*) : 0 mm. —17.8 — —6.7° C. (*10 — 20° F.*) : 6.4 mm. (*1/4"*)	Rail ends : by gas welding.
29 mm. (*1 1/8"*). 4	Suspended.	Alternate.	0	Electric flash welding for re-conditioning battered rail ends.
25 mm. (*1"*). 6	Supported.	Alternate.	5 mm. (*3/16"*).	Welding of rail ends. Lengthen the life by 1 to 3 years.
25 mm. (*1"*). 4	Suspended.	Alternate.	Over 28.9° C. (*84° F.*) : 0 mm. —17.8 — —11.1° C (*10 — 12° F.*) : 6.4 mm. (*1/4"*)	Welding of rail ends. Reforming of fish-plates.
27 mm. (*1 1/16"*). 4	Suspended.	Alternate.	Over 37.8° C. (*100° F.*) : 0 mm. 37.8 — 23.9° C. (*100 — 75° F.*) : 1.6 mm. (*1/16"*). -17.8 — —3.9° C. (*10 — 25° F.*) : 6.4 mm.(*1/4"*).	Do.
25 mm. (*1"*). 4	Suspended.	Alternate.	A. R. E. A. standard.	Gas welding.
25 mm. (*1"*). 4	Suspended.	Alternate.	Do.	...
25 mm. (*1"*). 4	Uniform spacing.	Alternate.	Do.	Rail ends : built up by oxy-acetylene welding. Fish-plates : built up by electric arc welding.

TABLE 8 (I). Ra

RAILWAYS.	1						
	Rail.						
	Weight, kgr. per m. (*lb. per yard*) and sectional area, cm.² (*sq. in.*).	Standard length.	Cant of rail.	Welding.			Sectional area of a fish-p and ratio of the secti area of a pair of fish-pl to that of the rail.
				Method.	Length.	Joint gap.	
Pere Marquette	55.5 kgr. (*112 lb.*). 71.1 cm² (*11.02 sq. in.*).	11.887 m. (*39'*)	1 : 40	...	...	...	71.5 cm² (*11.08 sq. in.*) 1.01
New York Central	52.1 kgr. (*105 lb.*). 66.1 cm² (*10.26 sq. in.*). 65.0 kgr. (*127 lb.*). 80.5 cm² (*12.48 sq. in.*).	11.887 m. (*39'*)	1 : 40	...	...	...	57.2 cm² (*8.88 sq. in.*) 0.87 72.6 cm² (*11.28 sq. in.* 0 90
Pennsylvania	64.9 kgr. (*131 lb.*). 83.2 cm² (*12.9 sq. in.*). 75.4 kgr. (*152 lb.*). 96.1 cm² (*14.9 sq .in.*).	11.887 m, (*39'*)	1 : 40	...	...	...	67.1 to 82.6 cm² (*10.4 to 12.8 sq. in.*) 0.81 — 0.86.
Missouri Pacific	55.5 kgr. (*112 lb.*). 71.1 cm² (*11.02 sq. in.*).	11.887 m. (*39'*)	1 : 40	...	...	...	31.5 cm² (*4.89 sq. in.* 0.89
Southern Pacific	...	...	...	...	...	...	...
Delaware, Lackawanna and Western	64.9 kgr. (*131 lb.*). 82.7 cm² (*12.86 sq. in.*).	11.887 m. (*39'*)	1 : 40	...	...	...	41.8 cm² (*6.49 sq. in.* 1.01
Other countries.							
Entre Rios	37.2 kgr. (*75 lb.*). 48.3 cm² (*7.45 sq. in.*).	12.192 m. (*40'*)	Canted.	...	...	...	24.3 cm² (*3.77 sq. in.* 1.01
Central Cordoba	34.7 kgr. (*70 lb.*).	12.192 m. (*40'*)	1 : 20	...	...	...	...
Paulista	54.5 kgr. (*110 lb.*). 45 cm² (*6.98 sq. in.*).	13.716 m. (*45'*)	1 : 20	...	...	...	28.13 cm² (*4.35 sq. in* 0.81
Buenos Ayres and Pacific	34.7 kgr. (*70 lb.*). 44.3 cm² (*6.88 sq. in.*). 49.6 kgr. (*100 lb.*). 63.1 cm² (*9.8 sq. in.*).	12.5 m. (*41'*)	1 : 20	...	...	...	For 100-lb. rail : 30.1 cm² (*4.66 sq. in* 0.95

d rail joints. (*Contd.*)

2				
Rail joints.				
eter of fish bolts and nber of bolts applied to oint.	Type of joint.	Opposite or alternate?	Width of gap.	Method of repairing battered joints, and results obtained.
24 mm. (*15/16''*). ter over the threads : 25 mm. (*1''*). 6	Supported.	Opposite.	A. R. E. A. standard.	Rail ends : by electric and gas welding. Reformed fish-plates on unimportant lines.
24 to 25 mm. (*15/16'' to 1''*). 6	Supported.	Opposite.	...	Rail ends : by gas and electric arc welding. Fish-plates : by reforming, or insertion of shims. Satisfactory.
29 mm. (*1 1/8''*). 6	Supported.	Opposite.	...	Rails : by welding. Fish-plates : by reforming.
25 mm. (*1''*). 4	Uniform spacing. Suspended and supported.	Opposite.	...	Rail ends : by gas or electric welding. Fish-plates : by reforming or insertion of shims. Satisfactory.
...	...	...	...	...
24 mm. (*15/16''*). 6	Uniform spacing.	Opposite.	Maximum : 4.8 mm. (*3/16''*).	Rail ends : by electric welding. Fish-plates : by reforming. Satisfactory.
19 mm. (*3/4''*). 6	Supported.	On the straight : opposite. On curves : alternate.	Summer : 3 mm./12 m. Winter : 8 mm./12 m. Mean : 6 mm./12 m.	Shims.
19 mm. (*3/4''*). 4 — 6	Suspended.	Opposite.	Frosty days : 4 mm. Over 30° C. : 2 mm. Under 30° C. : 3 mm.	...
25 mm. (*1''*). 6	Supported.	Alternate.	—3°C. to 10°C. : 6.4 mm./13.716 m. 10 — 24° C. : 4.0 mm./13.716 m. 24 — 38° C. : 1.6 mm./13.716 m. Over 38° C. : 0 mm.	Shims.
25 mm. (*1''*). 4	Suspended.	Opposite.	...	Shims.

TABLE 8 (II). — Sleepers, bearing-plat

RAILWAYS.	3 Sleepers. Kind and size.	Percentage of treated sleepers used.	Number used per km.	Spikes and coach-screws. Kind and number per sleeper.	Special sleepers
Japan and China.					
Japanese Government . . .	Wooden. 20 × 14 × 213 cm. (7 7/8'' × 5 1/2'' × 7').	50	1 640	Dog spikes and coach-screws. 4	...
Chosen, Government-General.	Wooden.	Not used as a rule.	...	...	None.
Chinese Rys.	Wooden. 22.9 × 22.9 × 243.8 cm. (9'' × 9'' × 8'). Some steel sleepers.	Not used as a rule.	1 531	Dog spikes and coach-screws. 4	None.
Great Britain, Dominions and Colonies.					
London, Midland and Scottish	Wooden.	100	1 313	3 coach-screws per chair.	Tentatively ste sleepers.
London and North Eastern .	Wooden. 25.4 × 12.7 × 259.1 cm. (10'' × 5'' × 8' 6'').	100	1 313	6 chair screws.	Steel sleepers
Great Western	Wooden. 25.4 × 12.7 × 259.1 cm. (10'' × 5'' × 8' 6''). Steel sleepers. 500 000 pieces.	100	1 313	No dog spikes. Chairs are fastened to sleepers with two bolts.	...
Southern	25.4 × 12.7 × 259.1 cm. (10'' × 5'' × 8' 6'').	100	1 313	3 coach-screws per chair.	...
Great Northern	Wooden. 25.4 × 12.7 × 289.6 cm. (10'' × 5'' × 9' 6'').	100	1 313	3 coach-screws per chair.	...
Great Southern	25.4 × 12.7 × 274.3 cm. (10'' × 5'' × 9' 0'').	100	1 313	2 bolts per chair.	...
Canadian National	Wooden. 20.3 × 15.2 × 243.8 cm. (8'' × 6'' × 8').	72	1 988 to 2 019	4 dog spikes on the straight. 6-8 in curves.	None.
Canadian Pacific	Wooden. 17.8 × 22.9 × 243.8 cm. (7'' × 9'' × 8').	0 % and 100 %.	1 864	6 dog spikes.	None.
North Western (India) . . .	Wooden. 25.4 × 12.7 × 274.3 cm. (10'' × 5'' × 9').	76	1 330	Dog spikes. Intermediate sleepers : 6. Joint sleepers : 8.	Cast iron and s
Great Indian Peninsula . .	Wooden. 25.4 × 12.7 × 274.3 cm. (10'' × 5'' × 9').	0	1 367	...	Pot sleepers and plate sleep
East Indian	Wooden. 25.4 × 12.7 × 274.3 cm. (10'' × 5'' × 9').	0	1 250	2 — 4 dog spikes.	Cast iron and steel sleep

i-creep devices and rail braces.

4			5			6
Bearing (sole) plates.			Anti-creep devices.			Rail braces :
Type.	Base area.	Use of bearing plates.	Number applied to a rail length.	Notched fish-plates.	Other means used to prevent creep.	place where used.
Double-houldered.	16.0 × 22.5 cm. (*6 5/16'' × 9''*).	Partially.	8 — 12 for a 25-m. (*82'*) rail.	50 kgr. rail : None. 37 kgr. } All. 30 kgr. }	Wooden stakes or struts.	Curves sharper than 600 m. (*30 ch.*) radius, but gradually replaced by bearing plates.
lat, single-houldered.	...	Partially.	...	A few.	None.	Where necessary.
Inclined.	21.6 × 16.5 cm	Partially.	5 — 6	A few.	Several devices.	Not generally used.
Cast iron chairs.	Intermediate : 36.8 × 20.3 cm. (*1' 2 1/2'' × 8''*). Joint : 36.8 × 25.4 cm. (*1' 2 1/2'' × 10''*).	On all sleepers.	...	None.	Steel keys.	...
Cast iron chairs.	Chairs : 36.8 × 20.3 cm. (*1' 2 1/2'' × 8''*).	On all sleepers.	45' — rail : 6. 60' — rail : 8 o 10.	None.	Steel keys instead of wooden blocks.	In terminals and yards.
Cast iron chairs.	Intermediate : 36.8 × 20.3 cm. (*1' 1 1/2'' × 8''*). Joints : 36.8 × 25.4 cm. (*1' 1 1/2'' × 10''*)	On all sleepers.	...	None.	Steel keys.	...
...	24.8 × 22.9 cm. (*9 3/4'' × 9''*).	On all sleepers.	6 — 8	None.	Steel keys.	...
...	25.4 × 20.3 cm. (*10'' × 8''*).	On all sleepers.	3 per 45' — rail.	None.	...	Some important sidings.
...	38.1 × 19.7 cm. (*15'' × 7 3/4''*).	On all sleepers.	None.	None.	...	...
Inclined, single-shouldered.	For 130-lb. rail : 30.5 × 17.8 cm. (*12'' × 7''*). For 100-lb. rail : 26.7 × 16.5 cm. (*10 1/2'' × 6 1/2''*).	On all sleepers.	Varying according to circumstances.	None.	...	Wooden braces for rails with wooden packings in the upheaved track.
Inclined, single-shouldered.	17.8 × 26.7 cm. (*7'' × 10 1/2''*).	On all sleepers.	Varying according to circumstances.	None.	...	...
Inclined, single-shouldered.	25.4 × 22.9 cm. (*10'' × 9''*).	On all sleepers.	8 — 12	None.	...	...
...	...	...	...	...	...	...
Inclined, single-shouldered.	For 90-lb. rails : 22.9 × 21.6 cm. (*9'' × 8 1/2''*). For 115-lb. rails : 21.6 × 24.8 cm. (*8 1/2'' × 9 3/4''*).	For soft wood sleepers.	3 — 4	Reducing.	...	...

TABLE 8 (II) — Sleepers, bearing-plate

RAILWAYS.	3 Sleepers. Kind and size.	Percentage of treated sleepers used.	Number used per km.	Spikes and coach-screws. Kind and number per sleeper.	Special sleepers.
Madras and Southern Mahratta	25.4 × 12.7 × 274.3 cm. (10'' × 5'' × 9').	0	...	...	Steel sleepers.
Bengal Nagpur	25.4 × 12.7 × 274.3 cm. (10'' × 5'' × 9').	0	1 367	4 dog spikes or coach-screws.	Steel and iron sleepers, and pla sleepers.
Burma Rys.	20.3 × 11.4 × 182.9 cm. (8'' × 4 1/2'' × 6').	0	1 367	4 dog spikes.	...
Ceylon Government	25.4 × 12.7 × 274.3 cm. (10'' × 5'' × 9').	0	1 367	4 dog spikes.	Concrete sleepers a unsatisfactory. Ir and steel sleep used tentatively.
New Zealand Government	Wooden. 20.3 × 12.7 × 213.4 cm. (8'' × 5'' × 7').	0	Straight sections 1 406 Curved sections 1 484	14 mm. (9/16'') : 4 or 13 mm. (1/2'') : 4. coach-screws with bearing plates.	... None.
New South Wales Government	Wooden. 22.9 × 11.4 × 243.8 cm. (9'' × 4 1/2'' × 8').	0	1 602	22 mm. (7/8'') dog spikes. 4 on the straight. 5 in curves.	
Sudan Government	22.9 × 12.7 × 198.1 cm. (9'' × 5'' × 6' 6'').	100	1 275	19 mm. (3/4'') coach-screws : 4.	...
Nigerian Ry.	Steel.	...	1 367	Used only on bridges and in turnouts.	Generally steel sleepers.
U. S. A.					
New York, Chicago and St. Louis	Wooden. 17.8 × 20.3 × 259.1 cm. (7'' × 8'' × 8' 6''). 17.8 × 22.9 × 259.1 cm. (7'' × 9'' × 8' 6'').	75	2 019	4 dog spikes.	Iron chairs only on ash-pits
Southern Ry. Syst.	...	...	1 988	Dog spikes.	...
Reading Co.	17.8 × 22.9 × 259.1 cm. (7'' × 9'' × 8' 6'').	93	1 790	Dog spikes. 140 × 16 mm. (5 1/2'' × 5/8''). Generally : 6. Sharp curves : 8.	Tentatively a few i sleepers.
Northern Pacific	Wooden. 17.8 × 20.3 × 259.1 cm. (7'' × 8'' × 8' 6'').	90	2 019	14 × 14 × 152 mm. (9/16'' × 9/16'' × 6''). Straight : 6. Curves : 8.	...
Atchison, Topeka and Santa Fe	Wooden. 17.8 × 20.3 × 243.8 cm. (7'' × 8'' × 8').	100	2 019	Dog spikes. 14 × 152 mm. (9/16'' × 6''). Generally : 4. In curves : 6-8.	...
Baltimore and Ohio	Wooden. 17.8 × 20.3 × 259.1 cm. (7'' × 8'' × 8' 6''). 17.8 × 22.9 × 259.1 cm. (7'' × 9'' × 8' 6'').	95	1 850	Dog spikes : on the straight and in 1° curves : 8. Curves sharper than (R= 1 746 m.) 1° : 10.	...
New York, New Haven and Hartford	Wooden.	100	1 988	16 × 152 mm. (5/8'' × 6'') : 4 — 8.	...
Chicago, Burlington and Quincy	Wooden. 17.8 × 22.9 × 259.1 cm. (7'' × 9'' × 8' 6'').	100	1 969	Dog spikes 16 × 140 mm. (5/8'' × 5 1/2'') : 4.	...
Norfolk and Western	Wooden. 17.8 × 22.9 × 259.1 cm. (7'' × 9'' × 8' 6'').	75	2 019	10 dog spikes.	...

ıti-creep devices and rail braces. *(Contd.)*

4			5			6
Bearing (sole) plates.			Anti-creep devices.			Rail braces :
Type.	Base area.	Use of bearing plates.	Number applied to a rail length.	Notched fish-plates.	Other means used to prevent creep.	place where used.
...	...	...	8	...	...	...
...	...	...	6	...	Cast iron Zenith clips.	...
...	...	...	8	...	...	...
...	...	...	3	...	...	...
at, double-houldered.	15.2 × 21.1 cm. (6" × 8 5/16").	Partially.	...	...	...	...
Inclined, single-houldered.	24.5 × 20.3 cm. (9 3/4" × 8").	In curves under 402 m. in radius.	12 for 45' rails.	...	...	...
Inclined, double-houldered.	20.0 × 17.6 cm. (7 7/8" × 6 15/18").	On all sleepers.	4 — 10	...	...	...
Cast iron.	...	...	8	...	...	...
Inclined, double-houldered. 1 : 40	19.1 × 25.4 cm. (7 1/2" × 10").	On all sleepers.	4	A few.	...	...
...	...	...	...	...	...	...
Inclined, single-houldered.	19.1 × 27.9 cm. (7 1/2" × 11").	On all sleepers.	Generally : 6. Occasionally : 8.	None.	Broken stone ballast under sleepers.	None.
Inclined, single-houldered.	19.1 × 27.6 cm. (7 1/2" × 10 7/8").	On all sleepers.	Generally : 5 — 6. Double-track sections : 4.	A few.	...	Where necessary.
Inclined, single-houldered.	20.3 × 26.7 cm. (8" × 10 1/2").	On all sleepers.	6 — 8	...	...	...
Inclined, double-houldered.	19.1 × 35.6 cm. (7 1/2" × 14").	On all sleepers.	6	...	...	...
Inclined, single-houldered.	20.3 × 27.9 cm. (8" × 11").	On all sleepers.	8	...	...	Switches.
Inclined, double-houldered.	20.3 × 27.9 cm. (8" × 11").	On all sleepers.	...	...	...	...
Inclined, single-houldered.	20.3 × 34.3 cm. (8" × 13 1/2").	On all sleepers.	8 — 12	...	...	Switches.

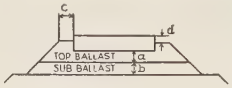
TABLE 8 (II). — Sleepers, bearing-plat

RAILWAYS.	3				
	Sleepers.				
	Kind and size.	Percentage of treated sleepers used.	Number used per km.	Spikes and coach-screws. Kind and number per sleeper.	Special sleepers
Delaware and Hudson	15.2 × 20.3 × 259.1 cm. (6'' × 8'' × 8' 6''). (17.8 × 20.3 × 259.1 cm. (7'' × 8'' × 8' 6''). 17.8 × 22.9 × 259.1 cm. (7'' × 9'' × 8' 6'').	100	1 790	Coach-screws: Straight: 4. Curves: 8.	...
Chesapeake and Ohio	Wooden. 17.8 × 22.9 × 259.1 cm. (7'' × 9'' × 8' 6'').	100	1 926	16 × 152 mm. (5/8'' × 6''). 4	...
Illinois Central	Wooden. 15.2 × 20.3 × 243.8 cm. (6'' × 8'' × 8').	100	1 988	Spikes: 16 × 146 mm. (5/8'' × 5 3/4'').	...
Great Northern	Wooden. 17.8 × 22.9 × 259.1 cm. (7'' × 9'' × 8' 6'').	61	2 013	16 × 152 mm. (5/8'' × 6''). 4	...
Atlantic Coast Line	Wooden. 17.8 × 22.9 × 259.1 cm. (7'' × 9'' × 8' 6''). 17.8 × 20.3 × 259.1 cm. (7'' × 8'' × 8' 6''). (15.2 × 20.3 × 259.1 cm. (6'' × 8'' × 8' 6'').	...	1 802	4 dog spikes.	...
Florida East Coast	Wooden. 17.8 × 22.9 × 259.1 cm. (7'' × 9'' × 8' 6'').	0	39'-rail 1 850 33'-rail 1 790	16 × 152 mm. (5/8'' × 6''). 4	...
Chicago, Rock Island and Pacific	Wooden.	100	1 988	4 dog spikes.	...
Pere Marquette	17.8 × 20.3 × 259.1 cm. (7'' × 8'' × 8' 6''). 17.8 × 22.9 × 259.1 cm. (7'' × 9'' × 8' 6'').	100	2 019	Coach-screws with bearing plates. Spikes without bearing plates.	...
New York Central	...	100	1 988	8	...
Pennsylvania	Wooden. 17.8 × 22.9 × 259.1 cm. (7'' × 9'' × 8' 6'').	83	1 849	8 — 10 dog spikes.	...
Missouri Pacific	Wooden. 17.8 × 20.3 × ... (7'' × 8'' × ...). 20.3 × 20.3 × ... (8'' × 8'' × ...). 20.3 × 22.9 × ... (8'' × 9'' × ...). 17.8 × 22.9 × ... (7'' × 9'' × ...).	100	2 019	4	...
Southern Pacific	...	...	...	...	...
Delaware, Lackawanna and Western	Wooden. 178 × 22.9 × 259.1 cm. (7'' × 9'' × 8' 6'').	100	2 010	6 dog spikes.	...
Other countries.					
Entre Rios	12 × 25 × 250 cm. (5'' × 8'' × 8' 3'').	0	1 394	4 dog spikes.	...
Cordoba Central	Wooden.	0	1 500	4 dog spikes.	...
Paulista	24 × 17 × 280 cm. (10'' × 7'' × 9' 2'').	0	1 603	8 coach-screws.	...
Buenos Ayres and Pacific	12 × 24 × 274 cm. (5'' × 10'' × 9').	0	1 520	22 mm. (7/8''). 4	...

ti-creep devices and rail braces. *(Contd.)*

4			5			6
Bearing (sole) plates.			Anti-creep devices.			Rail braces:
Type.	Base area.	Use of bearing plates.	Number applied to a rail length.	Notched fish-plates.	Other means used to prevent creep.	place where used.
Inclined, double-houldered.	20.3 × 34.3 cm. (*8" × 13 1/2"*).	On all sleepers.	...	...	Spring clips (each sleeper).	Switches.
Inclined, single-houldered.	19.1 × 31.8 cm. (*7 1/2" × 12 1/2"*).	On all sleepers.	4	A few.	Heel block for tongue rail.	Switches.
Inclined, single-houldered.	19.1 × 26.7 cm. (*7 1/2" × 10 1/2"*).	On all sleepers.	8	...	...	...
Inclined, single-nd double-houldered.	21.6 × 30.5 cm. (*8 1/2" × 12"*). 21.6 × 25.4 cm. (*8 1/2" × 10"*).	On all sleepers.	4 — 6	A few.	...	Switches.
Inclined, single-nd double-houldered.	17.8 × 25.4 cm. (*7" × 10"*).	On all sleepers.	4 — 6	A few.	...	...
Flat, single-houldered.	17.8 × 25.4 cm. (*7" × 10"*).	On all sleepers.	39'-rail : 8. 33'-rail : 6.	A few.	...	...
Inclined.	19.1 × 27.9 cm. (*7 1/2" × 11"*).	On all sleepers.	Single track : 6. Double track : 8.	...	...	...
Inclined, single-houldered.	19.1 × 31.8 cm. (*7 1/2" × 12 1/2"*).	On all sleepers.	4	A few.	...	Switches.
Inclined, double-houldered.	19.1 × 33.0 cm. (*7 1/2" × 13"*).	On all sleepers.	4 — 8	...	...	Sharp curves in yards.
Inclined, double-houldered.	19.1 × 37.5 cm. (*7 1/2" × 14 3/4"*). 19.1 × 39.4 cm. (*7 1/2" × 15 1/2"*).	On all sleepers.	6 — 8	...	...	...
Inclined, single-houldered.	20.3 × 25.4 cm. (*8" × 10"*). 20.3 × 27.9 cm. (*8" × 11"*).	On all sleepers.	12	...	...	...
...	...	...	...	...	...	...
Inclined, double-houldered.	19.1 × 33.0 cm. (*7 1/2" × 13"*).	On all sleepers.	12	..	...	...
...	...	...	6	A few.	...	...
...	...	...	1	A few.	...	...
Inclined, double-houldered.	36.0 × 17.1 cm. (*14 5/32" × 6 3/4"*).	On all sleepers.	...	...	...	...
Inclined, houlderless.	30.5 × 15.2 cm. (*12" × 6"*).	On all sleepers.	2 — 6	A few.	...	..

TABLE 8 (III). — Balla

RAILWAYS.	7 — Ballast. Section, cm. (*inches*).	7 — Ballast. Material.	7 — Ballast. Size, mm. (*inches*).	8 — Solid roadbe and results obtain
				
Japan and China.				
Japanese Government	*a* = 20 (*8''*). *c* = 23 (*9''*).	Broken stone or sieved gravel.	15 — 65 (*5/8'' — 2 9/16''*).	Used in long tunnels.
Chosen Government — General .	...	Sieved gravel.	10 — 80 (*3/8'' — 3 5/32''*).	...
Chinese Rys.	*a* = 23 (*9''*). *c* = 30 (*12''*).	Broken stone.	19 — 64 (*3/4'' — 2 1/2''*).	...
Great Britain, Dominions and Colonies.				
London, Midland and Scottish	*a* = 29 (*11 1/2''*). *b* = 10 — 15 (*4'' — 6''*).	Broken stone, slag and flint.	3 — 51 (*1/8'' — 2''*).	...
London and North Eastern . .	*a* = 30 (*12''*). Sub-ballast : ash.	Blast furnace slag.	19 — 64 (*3/4'' — 2 1/2''*).	...
Great Western	*a* = 10 (*4''*). *b* = 11 (*4 1/2''*). *c* = 23 (*9''*).	Broken stone, slag.	Top layer : 13 — 51 (*1/2'' — 2''*), 13 — 38 (*1/2'' — 1 1/2''*). Sub-layer : 102 — 203 (*4'' — 8''*).	...
Southern	*a* = 30 (*12''*). *c* = 15 (*6''*).	Broken stone.	51 — 19 (*2'' — 3/4''*).	...
Great Northern	*a* = 10 (*4''*). *b* = 38 (*15''*). *c* = 23 (*9''*).	Stone ballast. Stone pitching.	Under 57 (*2 1/4''*). Under 25 (*1''*).	...
Great Southern	*a* = 10 (*4''*). *b* = 15 (*6''*).	Broken stone.	51 — 19 (*2'' — 3/4''*).	...
Canadian National	*a* = 30 (*12''*). *b* = variable. *c* = 17 (*6 1/2''*). *d* = 5 (*2''*).	Broken stone, and gravel.	Broken stone : 19 — 70 (*3/4'' — 2 3/4''*). Gravel : 6 — 38 (*1/4'' — 1 1/2''*).	...
Canadian Pacific	*a* = 18 (*7''*). *b* = ... *c* = 24 (*9 1/2''*). *d* = 5 (*2''*).	Broken stone, and gravel.	Broken stone : 6 — 64 (*1/4'' — 2 1/2''*).	...
North Western (India)	*a* = 20 (*8''*). *b* = ... *c* = 46 (*18''*).	Broken stone.	51 and 38 (*2''* and *1 1/2''*).	...
Great Indian Peninsula	*a* = 30 (*12''*).	Broken stone.	51 — 38 (*2'' — 1 1/2''*).	...
East Indian	*a* = 25 (*10''*). *c* = 15 (*6''*).	Broken stone.	Under 51 (*2''*).	...
Madras and Southern Mahratta.	*a* = 18 (*7''*).	Broken stone and river gravel.	Broken stone : 51 (*2''*).	...

adbed and guard rails.

9	10			
	Guard rails.			
ethod used to prevent wear of rails, and results obtained.	Where are they used?	On which rail (inner or outer) are they used?	Difference in level, mm. (*inches*).	Minimum flangeway, mm. (*inches*).
ubrication and medium-manganese rails. Both methods satisfactory.	On curves sharper than 300 m. (*15 ch.*) radius.	Either outer or inner rail.	Same level.	55 + widening of gauge.
Tentatively rail lubrication. Satisfactory.	...	...	..	...
...	...	...	...	...
Special-steel rails and lubrication. Both methods satisfactory.	...	Inner rail.	Generally lower by 6 mm. (*1/4''*). On bridges : 25 (*1''*) lower.	Generally : 51 mm. (2''). On bridges : 67 (*2 5/8''*).
pecial-steel rails (medium-manganese, sorbitic and chrome-steel). Lubrication. Both methods satisfactory.	On curves sharper than 200 m. (*10 ch.*) in radius.	Inner rail.	Same level.	51 (2'').
pecial-steel; results not satisfactory. Lubrication satisfactory.	On curves sharper than R = 200 m. (*10 ch.*).	Inner rail.	Same level.	45 (*1 3/4''*).
Manganese steel and lubrication. Both methods satisfactory.	Do.	Do.	Do.	Do.
...	Do.	Do.	Do.	Do.
...	Do.	Do.	...	51 (2'').
...	On bridges.	...	...	..
...	...	...	...	...
...	On curves sharper than 8° R = 218 m. (*10.9 ch.*).	Inner rail.	Same level.	54 (*2 1/8''*).
Lubrication.	On bridges.	...	...	...
Lubrication; results unsatisfactory.	On curves sharper than 8° R = 218 m. (*10.9 ch.*).	Do.	Same level.	45 (*1 3/4''*).
...	Where necessary.	Do.	...	...

TABLE 8 (III). — Balla

RAILWAYS.	7			8
	Ballast.			Solid roadbe and results obtain
	Section, cm. (*inches*).	Material.	Size, mm. (*inches*).	
Bengal Nagpur	*a* = 8 (*3''*). *b* = 17 (*6 3/4''*).	Broken stone and cinder.	76 — 13 (*3'' — 1/2''*).	...
Burma Rys.	*a* = 15 (*6''*). *b* = 5 (*2''*). *c* = 30 (*12''*).	Broken stone.	38 (*1 1/2''*). 13 (*1/2''*).	...
Ceylon Government	*a* = 20 (*8''*). *b* = 30 (*12''*).	Broken stone.	51 (*2''*).	...
New Zealand Government	*a* = 23 (*9''*). *c* = 0.	Fine gravel or broken stone.	64 (*2 1/2''*).	...
New South Wales Government	*a* = 18 (*7''*). *c* = 41 (*16''*).	Broken stone.	51 — 19 (*2'' — 3/4''*).	...
Sudan Government	*a* = 23 (*9''*). *c* = 46 (*16''*).	Sieved gravel and broken stone.	64 — 6 (*2 1/2'' — 1/4''*).	...
Nigerian Ry.	*a* = 20 (*8''*).	Broken stone.	51 (*2''*).	...
U. S. A.				
New York, Chicago and St. Louis	*a* = 28 (*10''*).	Broken stone and slag. Sieved gravel.	25 — 64 (*6'' — 2 1/2''*). 3 — 38 (*1/10'' — 1 1/2''*).	...
Southern Ry. Syst.	...	Broken stone and slag.	...	...
Reading Co.	*a* = 30 (*12''*). *b* = 30 (*12''*). *c* = 15 (*6''*). *d* = 4 (*1 1/2''*) at centre. 13 (*5''*) at end.	Broken stone.	64 — 25 (*2 1/2'' — 1''*).	...
Northern Pacific	*c* = 15 (*6''*). *d* = 0.	Washed or unwashed gravel.	64 — 6 (*2 1/2'' — 1/4''*).	...
Atchison, Topeka and Santa Fe.	*a* = 30 (*12''*). *c* = 15 (*6''*). *d* = 3 (*1''*).	Broken stone, slag and gravel.	Broken stone : 13 — 64 (*1/2'' — 2 1/2''*). Slag : 6 — 64 (*1/4'' — 2 1/2''*). Gravel : No. 4 mesh. 38 (*1 1/2''*).	...
Baltimore and Ohio	*a* = 23—30 (*9''—12''*). *b* = ... *c* = 0. *d* = 4 (*1 1/2''*).	Broken stone, slag and gravel.	64 — 25 (*2 1/2'' — 1''*).	...
New York, New Haven and Hartford	*a* = 30—36 (*12''—14''*).	Broken stone.	A. R. E. A. specification.	...
Chicago, Burlington and Quincy.	*a* = 30 (*12''*). *c* = 20 (*8''*). *d* = 0 at centre. 4 (*1 1/2''*) at end.	Gravel, sand, broken stone, sieved chat, slag.	Maximum : 38 (*1 1/2''*).	...
Norfolk and Western	*a* = 38 (*15''*). *c* = 0. *d* = 0 at centre. 8 (*3''*) at end.	Broken stone, slag and gravel.	57 — 13 (*2 1/4'' — 1/2''*).	Only in tun
Delaware and Hudson	*a* = 30 (*12''*). *c* = 0. *d* = 6 (*2 1/2''*). 0 at centre.	Broken stone (new lines). Cinders (old lines).	70 — 19 (*2 3/4'' — 3/4''*).	...

ıdbed and guard rails. (*Contd.*)

9	10			
	Guard rails.			
thod used to prevent wear of rails, and results obtained.	Where are they used?	On which rail (inner or outer) are they used?	Difference in level, mm. (*inches*).	Minimum flangeway, mm. (*inches*).
...	On curves sharper than R = 269 m. (*13.5 ch.*).	Do.	2 mm. (*3/32"*).	48 (*1 7/8"*).
...	On curves sharper than 12° R = 145 m. (*12 ch.*).	Do.	8 (*5/16"*).	41 (*1 5/8"*).
...	On curves sharper than R = 603 m. (*30 ch.*).	Do.	Same level.	60 (*2 3/8"*).
...	...	...	...	...
Lubrication.	...	...	...	...
Lubrication; results unsatisfactory.	...	...	...	...
Special-steel rails satisfactory.	...	...	...	...
Hardening of rail ends, lubrication.	..	...	...	..
...	...	...	...	..
Lubrication.	...	...	...	..
Lubrication. Life of rail lenghtened by 25 — 50 %.	..	...	..	..
Neither medium manganese-steel rails nor lubrication have given satisfaction.	...	...	...	..
Lubrication.	..	...	...	..
Lubrication. Life of rail lengthened 5 — 10 years.	...	...	...	...
Lubrication; satisfactory.	...	...	...	..
Lubrication.	On curves sharper than 10° (R = 175 m.).	Inner rail.	Same level.	64 (*2 1/2"*).
Lubrication.	Bridges.	Both rails on bridges.	Same level.	...

TABLE 8 (III). — Balla

RAILWAYS.	7			8
	Ballast.			Solid roadbe and results obtain
	Section, cm. (*inches*).	Material.	Size, mm. (*inches*).	
Chesapeake and Ohio	*a* = 30 (*12''*). *c* = 15 (*6''*). *d* = 5 (*2''*).	Broken stone, sieved gravel.	64 — 19 (*2 1/2'' — 3/4''*). 38 — 25 (*1 1/2'' — 1''*).	...
Illinois Central	*a* = 30 (*12''*). *c* = 15 (*6''*). *d* = 0 at centre. 5 (*2''*) at end.	Broken stone, slag, gravel, chat.	Broken stone and slag : 64 — 16 (*2 1/2'' — 5/8''*). Gravel : 45 (*1 3/4''*) — 0.	...
Great Northern	*a* = 30 (*12''*). *c* = 30 (*12''*). *d* = 0 at centre. 5 (*2''*) at end.	Gravel.	< 51 (*2''*).	...
Atlantic Coast Line	*a* = 46 (*18''*).	Broken stone and slag.	64 — 13 (*2 1/2'' — 1/2''*).	...
Florida East Coast	*a* = 20 (*8''*).	Broken stone, slag and cinders.	51 — 13 (*2'' — 1/2''*).	...
Chicago, Rock Island and Pacific	*a* = 61 (*24''*).	Broken stone, gravel and chat.	A. R. E. A. specification.	...
Pere Marquette	*a* = 25 (*10''*). *c* = 15 (*6''*). *d* = 5 (*2''*).	Broken stone and sieved gravel.	A. R. E. A. specification.	Used in main-track; satis tory.
New York Central	*a* = 30 (*12''*). *b* = 38 (*15''*). Min. 30 (*12''*). *d* = 3 (*1''*) at centre. 5 (*2''*) at end.	Broken stone, slag, gravel and cinders.	64 — 25 (*2-1/2'' — 1''*).	...
Pennsylvania	*a* = 30 (*12''*). *b* = 30 (*12''*). *c* = 30 (*12''*). *d* = 1 (*1/2''*) at centre. 4 (*1 1/2''*) at end.	Broken stone.	76 — 32 (*3'' — 1 1/4''*). 38 — 19 (*1 1/2'' — 3/4''*).	...
Missouri Pacific	*a* = 30 (*12''*). *c* = 15 (*6''*). *d* = 0 at centre. 8 (*3''*) at end.	...	64 — 19 (*2 1/2'' — 3/4''*).	...
Southern Pacific	...	...	...	...
Delaware, Lackawanna and Western	*a* = 20 (*8''*). *c* = ... *d* = 4 (*1 1/2''*) at centre. 6 (*2 1/2''*) at end.	Broken stone.	64 — 25 (*2 1/2'' — 1''*).	...
Other countries.				
Entre Rios	*a* = 25 (*10''*). *c* = 65 (*26''*).	Broken stone and gravel.	Broken stone : 100 mm. (*4''*).	...
Cordoba Central	*a* = 25 (*10''*).	Broken stone, slag and gravel.	...	...
Paulista	*a* = 46 (*18''*). *c* = 23 (*9''*).	Broken stone.	64 — 19 (*2 1/2'' — 3/4''*).	...
Buenos Ayres and Pacific	*a* = 27—33 (*11''—13''*). *c* = 30 (*12''*).	Broken stone.	Under 51 (*2''*).	Concrete slabs level crossing

dbed and guard rails. (*Contd.*)

9	10			
	Guard rails.			
thod used to prevent wear of rails, and results obtained.	Where are they used?	On which rail (inner or outer) are they used?	Difference in level, mm. (*inches*).	Minimum flangeway, mm. (*inches*).
Lubrication.	Bridges.	Inner rail.	Same level.	...
rication. Life of rails doubled.	...	...	...	...
ubrication. Satisfactory except in winter.	On bridges.	...	...	48 (*1 7/8*").
...	...	...	...	...
...	...	...	...	...
Lubrication. Satisfactory.	...	...	...	...
...	...	...	...	...
rication : Life of rails lengthened from 1 to 5 times. Manganese steel : Life of rails lengthened from 3 to 4 times.	On bridges.	Outer rail.	Same level.	57 (*2 1/4*").
rication : Life of rails on 3°—10° curve lengthened.	...	...	...	...
Lubrication. Satisfactory.	...	...	...	...
...	...	...	...	...
Lubrication.	...	...	...	...
Lubrication (tentatively).	Curves sharper than R = 250 m. (*12.5 ch.*).	Inner rail.	Same level.	44 (*1 3/4*").
...	...	...	...	...
...	...	...	...	...
...	Curves sharper than R = 500 m. (*25 ch.*).	Inner rail.	Same level.	64 (*2 1/2*").

is from 1.5 to 3.0, while the mean value is 2.1. There should of course be a proportionality between the linear weight of rails and the maximum axle load of locomotives operated over them. The kind of rail to be adopted on main lines is determined theoretically and empirically by the following considerations,

a) strength of rails.
b) riding condition.
c) maintenance costs.

a) *Strength of rails.*

It may be fairly said that the strength of the track is mainly determined by the kind of rails, though the size and number of sleepers used, the kind and depth of the ballast are also concerned. It must have ample stiffness and strength to support the maximum axle load operated upon it.

Now, suppose a locomotive and wagon with the wheel arrangement shown in figure 13; the maximum allowable axle load has been calculated for various kinds of rails. The results are shown in table 9, where the rail pressure D required to depress the sleeper by unit depth is assumed to be 12 000 kgr., the spacing of sleepers 600 mm., the allowable stress of rail steel 2 000 kgr./cm² for the vertical bending stress, and the dynamic increment of stress due to the train speed 100 %.

Fig. 13. — Assumed wheel arrangement of rolling stock.

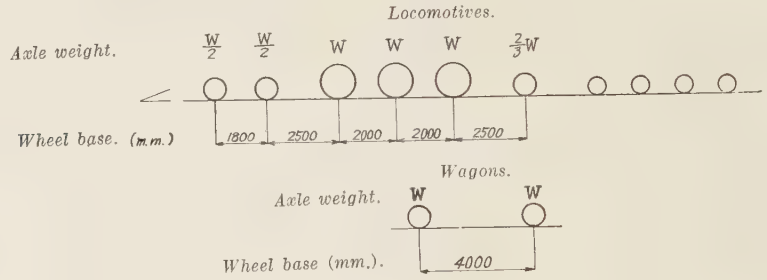


TABLE 9. — **Maximum allowable axle load.**

Weight of rail, kgr./m. *(lb./yard).*	Maximum allowable axle load (tons).	
	Locomotives.	Wagons.
30 *(60)*	13.9	13.4
37 *(75)*	17.8	15.5
45 *(90)*	20.7	19.2
50 *(100)*	26.8	21.6
55 *(110)*	33.0	25.6
65 *(130)*	40.9	30.6
76 *(152)*	56.1	38.4

The relation between the maximum allowable axle load and the weight of rail shown in table 9 is indicated graphically in Figure 14. Denoting the

Fig. 14 (1). — Weight of rail and maximum permissible axle weights of locomotives.

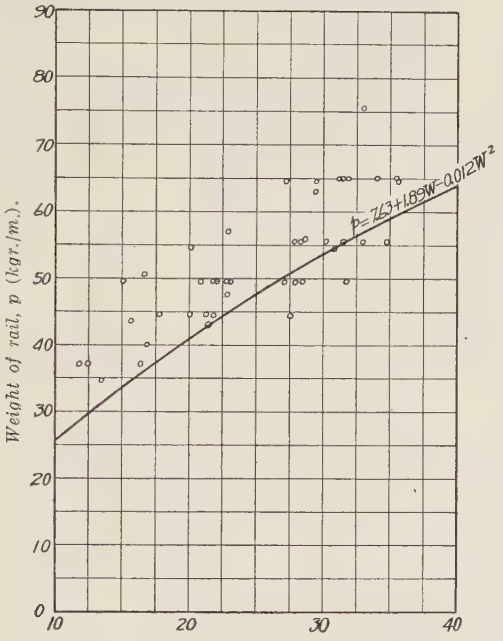
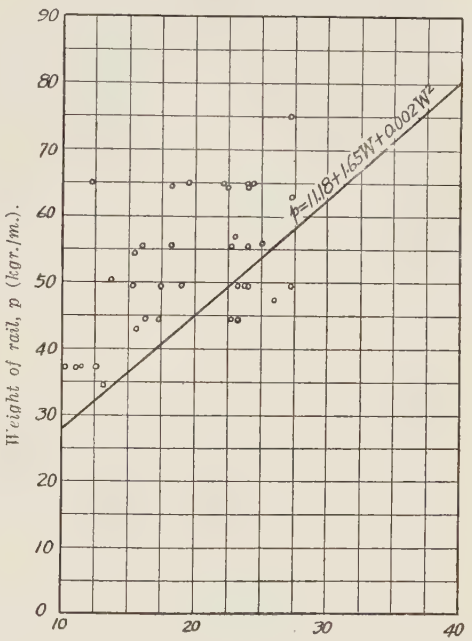


Fig. 14 (2). — Weight of rail and maximum permissible axle weight of wagons.



weight of rail by p kgr. per m. and the maximum allowable axle load by W tons, we get the following formulæ :

$$p = 7.63 + 1.89\ W - 0.012\ W^2 \text{ for locomotives,}$$
$$p = 11.18 + 1.65\ W + 0.002\ W^2 \text{ for wagons.}$$

The weight of rails, usually adopted by various railways, is heavier than that calculated theoretically by these formulæ, as is seen from Figure 14 in which the actual relation between the weight of the rail and the axle load is plotted. The rail section should be determined by taking into account not only its physical strength to support the load, but also the riding conditions and the maintenance costs. For this reason, most railways are replacing their old light rails by modern heavy ones.

The strength of the track increases rapidly as the weight of rail increases. Of course, the increase in the number of sleepers diminishes the stresses in the rail by a certain amount, but its effect is very slight. For example, in a track laid with 30 kgr./m. rails 2 500 sleepers must be used per kilometre to have the same strength as the track with 37 kgr./m. rail laid on 1 200 sleepers per kilometre.

The rail used on the main trunk line of the Japanese Government Rys. can bear the heaviest locomotive at the maximum allowable speed, but on the branch lines, the weight of the rail is often insufficient to permit the locomotive to operate at its maximum speed. In these cases, the operating speed is restricted so that the stress in the rails does not exceed the permissible limit.

Moreover, there is less danger of failure with heavier rails. Statistics on the

Japanese Government Rys. show that the number of failures of 50-kgr./m. rails is only 25 % that for 30 kgr./m. and 37 kgr./m. rails. It is easy to design strong fish-plates for heavy rails, because they have ample fishing height. On the Japanese Government Rys. the number of failures of fish-plates for 50-kgr./m. rails is 16 %, and for 37-kgr./m. rails 92 % as compared with 30 kgr./m. rails. In every respect the heavier rail is more reliable and may be used for the main lines carrying heavy loads at high speeds.

b) *Riding conditions.*

The weight of the rail has a great effect upon the vibration of vehicles, so that it is necessary to adopt a rail of 50 kgr./m. (100 lb./yard) at least, to minimize the vibration of rolling stock and ensure comfortable riding of high-speed trains.

The Japanese Government Railways investigated the vibration of a carriage body by means of a vibration recorder laid on the floor of the carriage. The intensity of the vibration on the track with the 37 kgr./m. rail was found to be about twice that with the 50 kgr./m. rail, even when the track was maintained in the best condition.

The heavy rail is necessary not only to improve riding conditions, but also to prevent accidents due high train speeds.

c) *Maintenance costs.*

Track carrying high-speed trains should always be kept in a good enough condition to ensure the safe and smooth operation of the trains. As the destructive action the vehicles exert upon the track increases in proportion to the square of the operating speed, the maintenance cost of track for high-speed operation would otherwise become excessive.

If the necessary maintenance force is not provided, premature destruction of track is inevitable, rough riding will ensue and the safety of operation may be endangered.

The heavy rail can save much of the track maintenance cost and stand longer use than the lighter one; besides it increases the life of sleepers and other track materials, making it economical in spite of its higher initial cost.

The Japanese Government Rys. have investigated for years the economic value of various kinds of rail laid on a test track. As a result, as shown in Table 10, the advantage derived from the adoption of the heavier rail becomes more prominent as the tonnage carried increases.

TABLE 10. — **Ratio of the track maintenance labour for rails of different weights.**

Tonnage carried per year (tons).	Weight of rail.		
	30 kgr./m.	37 kgr./m.	50 kgr./m.
	%	%	%
1 000 000	100	87	78
2 000 000	100	87	78
3 000 000	100	86	77
4 000 000	100	86	77
6 000 000	100	85	76
8 000 000	100	85	74
10 000 000	100	84	73
12 000 000	100	83	72

The ratio as regards track materials, excluding rails, renewed per year, is as shown in Table 11.

TABLE 11. — **Ratio of track materials renewed per year.**

Materials.	Weight of rail.		
	30 kgr./m.	37 kgr./m.	50 kgr./m.
	%	%	%
Ballast	100	52	24
Sleepers.	100	78	69
Fish-plates.	100	24	1
Track bolts	100	50	8
Spikes	100	85	70

The rails laid in straight and level sections of the Japanese Government Rys. are supposed to be able to bear the passage of the total tonnage shown below until they are renewed due to wear of their sections :

For 30-kgr./m. rails . . . 66 600 000 tons,
for 37 » . . . 115 200 000 tons,
for 50 » . . . 177 800 000 tons.

The total expenditure per year for each kind of rail, including the cost of maintenance labour, track materials, amortization and the interest on the cost for relaying rails, is compared in Table 12.

TABLE 12. — **Ratio of the total expediture per year for rails of different weights.**

Tonnage carried per year (tons).	Weight of rail.		
	30 kgr./m.	37 kgr./m.	50 kgr./m.
	%	%	%
1 000 000	100	92	94
2 000 000	100	90	90
3 000 000	100	88	87
4 000 000	100	87	84
6 000 000	100	85	81
8 000 000	100	84	78
10 000 000	100	83	76
12 000 000	100	82	75

As can be seen from the table, on the Japanese Government Rys., the 30-kgr./m. rail is uneconomical in any case; the 37-kgr./m. rail is advantageous for track carrying a total tonnage of less than 2 000 000 per year, while for all other track sections the 50-kgr./m. rail is the more economical.

(II) Length of rails.

Most Railway Administrations in the United States adopt as the standard length of rail 39′ (11.887 m.), with the exception of a few Railways using longer rails, such as 60′ or 66′.

The four main-line Railways of Great Britain adopt the standard length of 60′ (18.288 m.) and only the London and North Eastern uses 90′ (27.432 m.) long rails on several sections. The Canadian Pacific and the Canadian National have adopted 39′ (11.887 m.) as standard length of rails, and Railways in India 36′ (10.973 m.), 40′ (12.193 m.), or 42′ (12.802 m.).

The Japanese Government Railways formerly used 12-m. (39′) and 10.058 m. (33′) rails as standard lengths, but acknowledging the merits of the longer rail, they have fixed the standard lengths at 25 m. (82′) for 37 and 50-kgr./m. rails, and 20 m. (65′ 6″) for 30 kgr./m. rails. The standard lengths were decided upon after many years' investigations into the various problems concerning the use of long rails.

The rail joint is the weak point in the track, and needs most frequent tampings to prevent rail end batter, which causes vibration of rolling stock and uncomfortable riding.

Therefore, it has been the ardent desire of the permanent-way maintenance officers to reduce the number of joints where conditions permit.

But the length of rails is restricted not only by the capacity of the rolling mill and the means of transportation (especially by ship) but also by the width of the joint gap to be provided for expansion due to temperature changes. The longer rail necessarily needs a larger joint opening which causes violent shocks to vehicles when high-speed trains pass over it, resulting in excessive wear of rail ends and ultimate deterioration of the track as a whole. These drawbacks have long restricted the adoption of comparatively long rails.

It has been proved, however, after various experiments made upon long rails and welded rails, that it is not necessary to provide the full theoretical amount of joint opening as calculated by a formula which ignores the frictional resistance of rails to free expansion and contraction. In fact, rails without any joint openings would be able to resist the axial force due to temperature rise without fear of buckling, till this force reaches a certain limit.

Thus the long rail has come to be utilized by many Railway Administrations, and especially in Europe, where rails as long as 18, 24 and 30 m. (59′ 5/8″, 78′ 9″ and 98′ 5 1/8″) are now widely adopted.

In this respect, the Summary of Question II discussed at the XIth Session (Madrid, 1930) of the International Railway Congress Association states that « the length of medium rails (of medium weight) can, without inconvenience, be increased to 24 m. (78′-9″), and research and tests should be continued with a view to increasing the length beyond 24 m. (if necessary by means of aluminothermic welding), particularly at special points of the line where the effects of expansion are less to be feared ».

The number of rail joints can be reduced by the use of longer rail lengths or by welding, and this is a subject to be studied most thoroughly, in connection with high-speed operation.

(III) Effect of rail length upon the vibration of rolling stock.

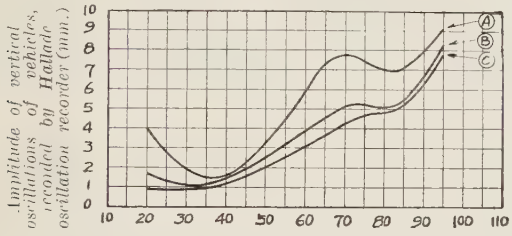
The maximum length of a rail is limited by the dimensions of the equipment in the rolling mill, and the capacity of the means of transportation. The longer a rail is, the better result it gives as regards oscillations in rolling stock, but it must be borne in mind that there is a certain length with which resonance

occurs between the oscillation due to rail joints and the self-oscillation of vehicles.

The Japanese Government Rys. have decided to adopt rails 20 m. and 25 m. long instead of the 10.058-m. (33′) and 12 m. (39′ 4 1/2″) rails that had been used until recently. These new standards have been adopted in order to reduce to a minimum the vibration of the various vehicles, taking the periods of their free vibration into account.

Figure 15 shows the amplitude of vertical vibrations recorded by the Hallade Recorder, laid on the floor of a passenger carriage travelling at various

Fig. 15. — Train speeds and amplitude of vertical oscillations of vehicles at various speeds.



A Coach with 4-wheeled bogies.
B Longer coach with 4-wheeled bogies.
C Coach with 6-wheeled bogies.

speeds. It can be seen that strong vibrations occur at a speed of 70 to 75 km. (43.5 to 46.6 miles) per hour. This is because the period of the forced oscillation due to the impact at the rail joint coincides with that of the free vertical vibration of rolling stock at those speeds. The period of free oscillation of coaches is about 0.5 second, and the distance travelled in one period is 9.70 m. at a speed of 70 km./h., and 10.40 m. at 75 km./h. so that there is co-incidence with the rail length.

The amplitude of the forced oscillation is damped out quite rapidly owing to the friction of the springs, but if impacts are imposed repeatedly with a certain period similar to the period of the free oscillation, it is gradually increased until it becomes dangerous. As the impact at the rail joint is the chief cause of the forced vibration of rolling stock, the distance between joints should be studied theoretically and practically.

Besides vertical vibration, there is lateral vibration, the period of which is concerned with the irregularity of the alignment of the track, the taper of the wheel tread, the design of bolster hangers, etc. It is about 0.7 second for coaches and has the characteristic of decreasing inversely in proportion to the increase in train speed. But the effect of rail length upon lateral oscillation is so slight that it needs not be considered when deciding the rail length.

The vertical oscillation of vehicles is composed of simple vertical motion and pitching motion. The periods of free vibration for various vehicles are shown in Table 13.

TABLE 13. — **Periods of free vibration.**

—	Locomotives.	Coaches.	Unloaded wagons.	Loaded wagons.
Period of simple vertical vibration (τ_u), *seconds*	0.4	0.7	0.3	0.5
Period of pitching τ_p, *seconds* . . .	...	0.6	0.3	0.5

If
L = rail length (in metres) travelled in one period of the forced vibration,
τ = period of free vibration in seconds,
V = train speed in km./hour,
S = period of impact due to rail joints in seconds,
then
$L = 1/36\ SV$.

When $S = \tau$ or 2τ resonance is set up; rolling stock will vibrate violently especially in the case of $S = \tau$. When $S = 1.5\tau$ free vibration will be cancelled by forced oscillation, and when $S \geqslant 2.5\ \tau$ the effect of the rail joint practically vanishes. Therefore, the rail length should not be $S = \tau$ or $S = 2\tau$, but $S = 1.5\ \tau$ or $S \geqslant 2.5\ \tau$ for the ruling speed.

The Japanese Government Rys. assumed a speed of 85 km./hour on sections laid with 50-kgr./m. and 37-kgr./m. rails, 70 km./hour with 30-kgr./m. rails for passenger trains, and 65 km./hour for goods trains.

The rail length L which gives the maximum or minimum amplitude calculated by the above formula is tabulated in the Table 14.

TABLE 14. — **Rail length giving the maximum or minimum amplitude (metre).**

Kind of vehicle.	Speed, in km./hour.	Period of free vibration, in seconds.	Rail length, in metres.			
			$S = \tau$	$S = 1.5\ \tau$	$S = 2\ \tau$	$S = 2.5\ \tau$
Locomotive	85	$\tau_u = 0.4$	9.5	14.2	18.9	23.6
	70	»	7.8	11.7	15.6	19.5
	65	»	7.2	10.8	14.5	18.0
Coach	85	$\tau_u = 0.7$	16.5	24.8	33.0	41.3
		$\tau_p = 0.6$	14.4	21.6	28.8	36.0
	70	$\tau_u = 0.7$	13.6	20.4	27.2	34.0
		$\tau_p = 0.6$	11.9	17.8	23.7	29.6
Unloaded wagon . .	65	$\tau_u = \tau_p = 0.3$	5.4	8.1	10.8	13.5
Loaded wagon . . .	65	$\tau_u = \tau_p = 0.5$	9.0	13.5	18.0	22.6

When the rail length is greater than 17 m. (55′ 9 1/4″) resonance between free and forced vibrations of the primary order ($S = \tau$) is not set up while with a rail longer than 20 m. (65′ 7 3/8″) there is no fear of resonance in the case of locomotives and wagons. When the rail length becomes 41 m. (134′ 6 3/4″), resonance in passenger carriages also disappears, but this length is too great to be adopted as the standard. After careful consideration, the lengths of 25 m. (82′ 1/4″) for V = 85 km./hour and 20 m. (65′ 7 3/8″) for V = 70 km. (43.5 miles) per hour were adopted as the new standards which, as shown in the table, do not cause resonance at the prescribed speeds.

By the use of these long rails, the number of rail joints can be reduced from 84-100 to 45-50 per kilometere, a decrease of about 50 %. As the joint sleepers require two or three times the labour for tamping as compared with intermediate sleepers, the decrease in the number of rail joints causes a large reduction in the track maintenance costs. It may be assumed that by the use of long rails, there is a saving of 9 % in maintenance labour, and 4 % in track materials with 25-m. rails, and 8 % in labour and 3 % in materials in the case of 20-m. rails.

(IV) Resistance against buckling, and expansion gap for long rails.

The range of temperature variations in Japan extends from — 10° C. to 38° C. (14° F. to 100.4° F.) and the temperature of the rails changes accordingly from — 10° C. to 58° C. (14° F. to 136.4° F.). If rails of 25 m. (82′ 1/4″) length are laid so as to leave no expansion gap at the maximum temperature, the width of gap at the minimum temperature would be more than 17 mm. (11/16″) even though the combined resistance of the fish-plates and the roadbed against the contraction of rails were taken into account. Such a large joint opening not only causes heavy shocks to the rolling stock but quickens the wear of the rail ends and eliminates all the benefit derived from the use of long rails.

Many Railways in the United States prescribe the maximum amount of joint opening as 3/8″ (9.5 mm.) for the 39′ (11.889 m.) rail, while the London and North Eastern Railway limits the maximum gap to 5/8″ (15.9 mm.), even for the 90′ (27.432-m.) rail. It is desirable to keep the gap under 10 mm. (3/8″) and never above 15 mm. (19/32″).

It is general practice to lay long rails with joint openings which close up before the maximum temperature is reached. Expansion due to any further rise in temperature causes a compressive stress in the rail. Such an internal axial stress may be set up when the joint opening becomes less than the prescribed amount owing to rail creep, or when the grip of fish bolts and the friction of fish-plates hinders the free expansion or contraction of rails. Under these axial forces, the track would buckle and endanger safe operation unless it is restrained laterally by the ballast.

The Japanese Government Railways have carried out, a series of investigations about the resistance against buckling under various conditions, on a test track specially laid for the purpose. The various forms of buckled tracks are classified into the three types shown in Figure 16. In most cases, the form taken up is of type I, and next type II. On curved track almost all cases belong to type I.

The results of the compression tests are shown in Table 15. It may be concluded that the resistance against buckling varies remarkably with the linear weight of rail, and the resistance of the ballast and roadbed against the displacement of the fish-plates and the radius of the curve, and that the rail once buckled at any point, has a tendency to buckle easily again at that point under a relatively small axial load.

Fig. 16. Forms of track buckling.

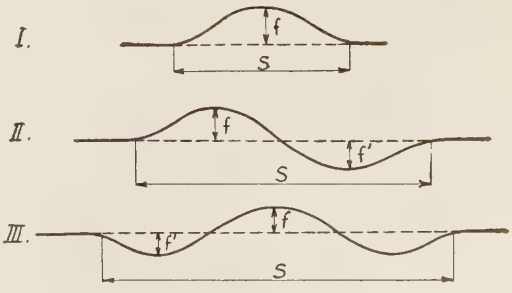


TABLE 15. — **Ultimate buckling strength obtained during the compression tests.**
Unit = ton.

Weight of rail, kgr./m.	Straight track.			Curved track (R = 500 m.)			Curved track (R = 300 m.)		
	max.	min.	mean	max.	min.	mean	max.	min.	mean
50	70.7	50.4	60.4	57.0	50.2	54.5	45.6	37.2	41.4
37	57.0	38.0	48.9	50.2	34.2	40.8	39.9	25.8	35.9
30	46.0	31.2	36.4	35.3	22.8	30.6	35.7	27.4	31.0

Assuming the form of the track after buckling to be as shown in Figure 17, the force required to make it yield is calculated by the principle of virtual work.

$$\left.\begin{aligned} P_0 &= EFD + \frac{2\pi^4 EJ\frac{f}{S^3} + \frac{1}{2}gS + \frac{2M}{p}}{\frac{\pi^2 f}{2S} + \frac{S}{2R}} \\ P_0 &= EFD + \frac{\frac{EF}{2}D^2 + 3\pi^2 EJ\frac{f^2}{S^4} - \frac{1}{2}gf}{\frac{\pi^2 f^2}{4S^2} - \frac{f}{2R}} \\ \text{and} \quad D &= \sqrt{\left(\frac{rS}{2EF}\right)^2 + \frac{r}{EF}\left(\frac{\pi^2 f^2}{4S} + \frac{fS}{2R}\right)} - \frac{rS}{2EF} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (1)$$

wherein

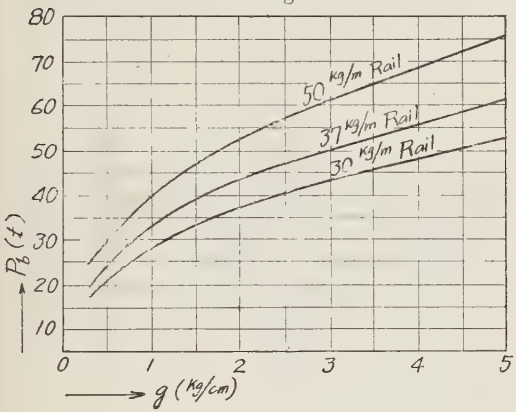
P_0 = the axial force which caused buckling,

Fig. 17.

E = modulus of elasticity of rail steel,
F = sectional area of rail,
J = moment of inertia of rail with respect to the vertical axis of the rail section,
R = radius of curve,
$2r$ = resistance against longitudinal displacement of the track per unit length,
$2g$ = resistance against the lateral displacement of track per unit length,
M = resisting moment against the rotational displacement between a sleeper and rail,
f = maximum displacement of the track from its initial position,
S = length of the buckled part of track.

Assuming the value of f, the value of P_0 and S are calculated by equation (1). The least value of P_0, which is denoted by P_b is shown in Figure 18, the value of r being assumed to be 3 kgr./cm.

Fig. 18. — Resistance of straight track to buckling.



The value of M becomes as high as 6 000 kgr./cm. when spikes are rigidly driven in a new sleeper, but in the actual track it is almost negligible. The value of g is 1.4-2.1 kgr./cm. for the narrow-gauge track, but when the upper part of the sleeper is exposed owing to scarcity of the ballast, the resistance decreases rapidly and if the ballast is removed to the lower surface of the sleepers the resistance decreases to one third of the ordinary value.

In the ordinary straight track the 50 kgr./m. rail can safely resist an axial load of 40 tons; 37 kgr./m. rail 33 tons, and 30 kgr./m. rail 28 tons.

Of course, the resistance against buckling on curved track is smaller than that on straight lines, and may be supposed to be as follows :

For R	=	500 m. . . .	90-94 %
For R	=	300 m. . . .	82-90 %
For R	=	200 m. . . .	72-82 %
For R	=	150 m. . . .	64-72 %

When the ballast is removed down to the bottom surface of the sleepers, the resistance decreases to 60 % on the straight and 48 % in curved track. The resistance of the ballast to lateral displacement increases in proportion to the width of the ballast at the end of the sleeper, but in the case of 20 × 14 × 213 cm. (7 7/8″ × 5 1/2″ × 7′ 0″) sleeper, the maximum resistance is attained when the width of the ballast is 40-45 cm. (15 3/4″ to 17 11/16″). A further increase in width is insignificant so far as the value of the lateral resistance is concerned.

The frictional resistance of the ballast on either side of the sleeper has no small influence upon the resistance to lateral displacement of the sleepers. Filling the space between sleepers with ballast up to the top surface of the sleepers markedly increases the lateral resistance and prevents buckling of the track.

(V) Determination of joint opening for long rails.

When a length x_0 from the end of the rail is elongated by a temperature rise of Δ_t, the maximum axial force in the rail is expressed by the following formula,

$$P = EF\,\beta\,\Delta t = (R) + \int_0^{x_0} r dx,$$

where

F = sectional area of rail,
E = modulus of elasticity of rail steel,
β = linear expansion coefficient of rail,
(R) = resistance between rail and fish-plates,
r = resistance against the longitudinal displacement of rail and rail supports.

If δ is the amount of displacement of the rail ends, then

$$\delta = \beta\, x_0\, \Delta t - \frac{(R)}{EF}\, x_0 - \frac{1}{EF}\int_0^{x_0} r\, x\, d\, x.$$

Putting

$$r = c\,\delta^n = c'\,x^n,$$

we get

$$P = EF\,\beta\,\Delta t = (R) + \frac{r\,x_0}{n+1}$$

$$\delta = \beta\,x_0\,\Delta t - \frac{x_0}{EF}\left((R) + \frac{r\,x_0}{n+2}\right).$$

The maximum value of P and δ occurs when $x_0 = \frac{L}{2}$, where L is the rail length;

then

$$\left(P = (R) + \frac{r}{n+1}\,\frac{L}{2}\right)$$

$$\delta = \beta\,\Delta t\,\frac{L}{2} - \frac{L}{2\,EF}\left((R) + \frac{r}{n+2}\,\frac{L}{2}\right).$$

If at a certain temperature the rail ends are in contact with each other and then a further temperature rise Δt_0 occurs, the value of the maximum axial force P_m may be calculated by the following formula :

$$P_m = (R) + \frac{r}{n+1}\,\frac{L}{2} + EF\,\beta\,\Delta t_o$$

$$\Delta t_o = \frac{P_m - \left((R) + \frac{r}{n+1}\,\frac{L}{2}\right)}{EF\,\beta}.$$

If P_m represents the maximum allowable axial force, and T_m the maximum temperature of the rails, then the latter should be laid so that the joint opening is zero at the temperature $(T_m - \Delta t_0)$.

If ϵ denotes the joint opening at the temperature T_s and becomes zero at the temperature $(T_m - \Delta t_0)$,

$$\varepsilon = 2\,\delta = \beta\,L\,(T_m - \Delta t_o - T_s) - \frac{L}{EF}\left((R) + \frac{r}{n+2}\,\frac{L}{2}\right).$$

Substitung the value of Δt_0, we get

$$\varepsilon = \beta\,L\,(T_m - T_s) - \frac{L}{EF}\left(P_m - \frac{r}{(n+2)(n+1)}\cdot\frac{L}{2}\right).$$

The Japanese Government Rys. assumed $T_m = 58°$ C. $= 136.4°$ F. and the value of L, F and P_m as shown in the following table :

Weight of rail, kgr./m.	Rail length L (m.).	Sectional area F (cm²).	Allowable axial force, P_m (tons).
50	25	64.35	35
37	25	47.30	27
30	20	38.28	22

Substituting

β = 0.0000114.
E = 2 100 000 kgr./cm,
(R) = 10 tons,
n = 1/4,
r = 3 kgr./cm².

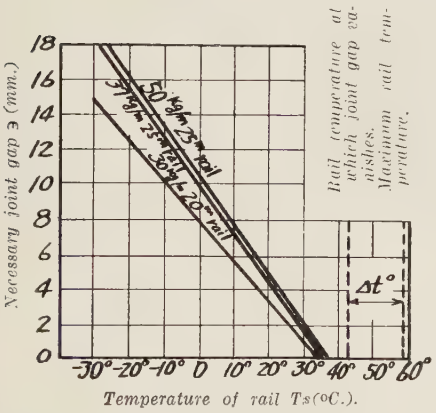
in the foregoing formula, we have calculated the relation between the joint opening ε and the temperature of rail T_s, as shown in Figure 19. The rails may be laid without openings at $T_s = 35°$ C. $= 95°$ F.

But the temperature of the rails is higher than that of the air, and there is a relation between them as indicated in Figure 20. For example, the temperature of 58° C. in the rail corresponds to 38° C. of the air temperature. If the abscissa of Figure 19 is converted into the air temperature, the results are as shown in Figure 21.

The width of the joint gap is decided according to the allowable axial force P_m; for example, in the case of 50 kgr./m. rail, of 25-m. length, the neces-

sary joint opening at 0° C. is 16.8 mm. when $P_m = 0$, and is reduced to 10.3 mm. when $P_m = 35$ tons, i.e. reduced by 40 %. Thus, by allowing axial force to the rails, various difficulties inherent to the excessive gap are avoided. But the greater the allowable axial force is, the stronger the construction of the track should be and the greater the attention to be given to maintenance work, in order to prevent buckling.

Fig. 19.


Necessary joint gap ε (mm.)
50 kg/m 25 m rail
37 kg/m 25 m rail
30 kg/m 20 m rail
Rail temperature at which joint gap vanishes. Maximum rail temperature.
Δt°
Temperature of rail Ts(°C.).

The use of heavy rails is most effective in preventing buckling, but filling the space between sleepers with ballast up to the top surface of the sleepers is also necessary.

Fig. 22.

A.

Size: 20 × 14 × 213 cm.

B.

Depth of removed ballast and minimum buckling load.

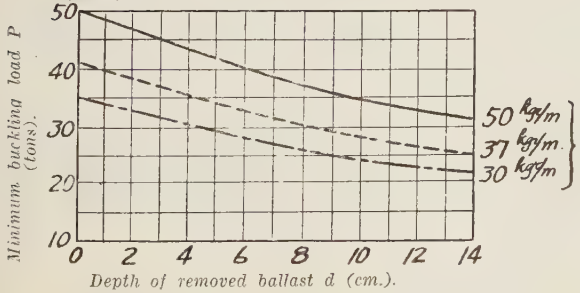


Fig. 20.

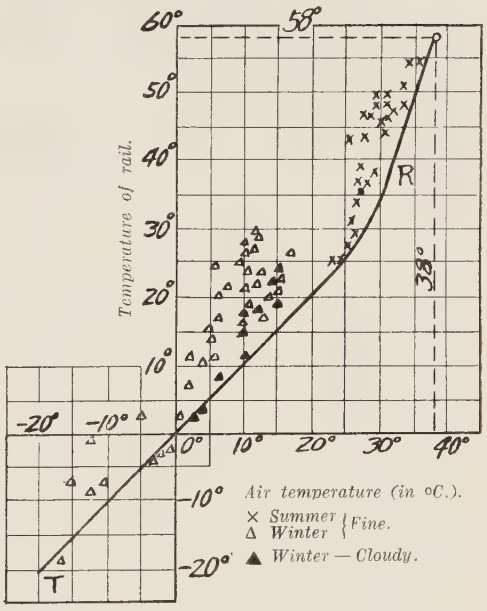
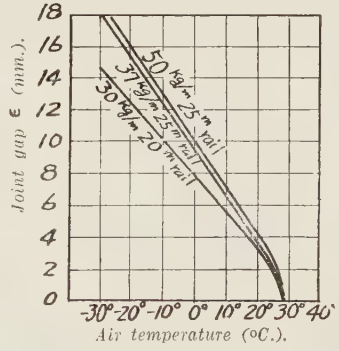
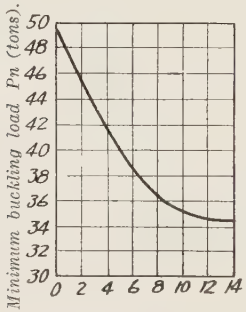


Fig. 21.



The removal of ballast as indicated in Figure 22 markedly reduces the lateral resistance, this reduction being proportional to the exposed depth of the sleeper. When the ballast is removed for a certain length down to the bottom of the sleepers, the buckling force P*n*

Fig. 23.



decreases as shown in Figure 23. Therefore the removal of ballast in hot weather is dangerous practice on track laid with long rails.

(VI) **Welding of rails.**

The standard length of rails adopted by the Delaware and Hudson RR. is 39′ (11.889 m.) but this Administration recommends the use of longer rails, welding its own into extra-long sections by the thermit-pressure method; the length after welding is 500′ (152.40 m.) at least, and the greatest length welded is 6 983′ (2 128.40 m.). Between the welded rails there is an opening of only 1/4″ (6.3 mm.) to insert the insulating fibre for track-circuit purposes. The advantages claimed for welding by this Railway are : easier maintenance of rail joints, decreased rail end batter, longer life of rails, savings in track maintenance owing to decreased rail creep, elimination of rail bonds, improvement of riding conditions, savings on rolling stock maintenance costs, and on power consumption, etc.

The London and North Eastern Ry. has tentatively adopted welded rails. The Southern Railway welds two lengths, each of 60′ (18.30 m.), by the thermit process, into 120′ (36.60 m.) rails, the expansion gap between such welded rails being 5/16″ (8 mm.).

The New South Wales Government Rys. welded five rails of 45′ standard length by the thermit-pressure method thus obtaining a rail or 225′ (68.60 m.), and tentatively welded up a length of 1 800′ (548.60 m.). These Railways reported that the welded rails ensure comfortable riding, reduction in maintenance costs and decreased damage to track. They have also determined the range of temperatures within which longer rails may be laid, and forbid laying such rails at a low temperature in order to prevent buckling in hot weather.

The welding together of rails has been the practice for a long time on tramway lines in order to reduce maintenance cost of paved track, and satisfactory results were obtained; but the application of this method on track for heavy loads moving at high speeds requires further study.

Not only are rails welded together in order to reduce the number of joints, but battered rail ends or worn crossings are also reconditioned by welding. Welding for reconditioning worn rails is adopted by almost all Administrations in the United States and Canada, and both the electric arc and the oxy-acetylene process are employed with satisfactory results. These methods prolong the life of rails by several years, improve riding conditions and save maintenance costs.

With the oxy-acetylene process the operator welds the rod to the rail and at the same time finishes the surface by grinding. After welding, the welded part

is heat-treated and given the necessary hardness and ductility.

In electric arc welding, it is the usual practice at present to preheat the rail, and after welding is completed, to carefully grind the welded parts.

The oxy-acetylene process has the merits of requiring only simple apparatus of lower cost than electric arc welding while providing smoothness of finished surface and uniformity of results due to the heat treatment. But the drawback to this process is that the rail head must be heated for a long time, and the metal is apt to undergo a change of internal structure.

The electric arc welding process needs a relatively expensive generating and welding apparatus. This welding technique is more difficult than gas welding, and grinding is always necessary but on the other hand, it is more efficient as there is no waste of time for heat treatment. When welding is done on a large scale, electric arc welding is said to be more economical per joint dealt with than gas welding. Both these methods have merits and drawbacks and should be selected according to local conditions.

With the exception of the United States and Canada, most of the countries covered by this report have little experience in rail welding.

As welding is a most economical method for repairing battered rail ends, the method should be improved as the results of further investigations.

(VII) Canting of rails.

The wheel tyre of rolling stock operated on most railways has a conical tread, usually with a taper of 1/20. The mean amplitude of the lateral oscillation of vehicles with conical tread is comparatively larger than that with cylindrical tread, but the conical tread has the following merits :

1. The centre line of the rolling stock has a tendency to coincide with that of the track;

2. It does not cause violent oscillations;

3. In curved track, the wheel is in contact with the outer rail at the tread of larger radius and with the inner rail at the tread of smaller radius; therefore the slip between wheel and rail is minimized.

If the rail is canted to suit the taper of the tyre, the contact area between tyre and rail head becomes larger and tyre wear decreases. Furthermore the bearing stress between rail and sleeper is distributed more uniformly because the resultant of the vertical wheel load and the side pressure passes nearly through the centre of the rail base.

The Japanese Government Rys., the Chinese Rys., and the Railways in Great Britain, Dominions and Colonies, lay their rails with a cant of 1/20, but in the United States most Railways lay their rails with a cant of 1/40 to 1/44, and only a few with a cant of 1/20. The Northern Pacific Ry. is the only one which adopts a cant of 1/88.

Rail cant is obtained by bearing plates.

9. Design of rail joints

(I) Cross sectional area and type of fish-plates.

The rail joint is the weak point of the track. The joint sleepers are apt to be unequally depressed under loads, and shocks are set up in vehicles at the joint. The labour necessary for tamping the sleepers near the joint amounts to almost half of the total labour required for tamping the whole track. Therefore, the reduction of the number of joints by the adoption of extra-long rails obtained by welding is a big step towards comfortable riding and savings in maintenance costs. But in view of the difficulties encountered for rolling and transporting very long rails, and their liability to buckling, it is impos-

sible, at present, to eliminate the joints; therefore every railway is trying to improve the design of the joint to give it as much rigidity as possible. The fish-plates should have the same rigidity as that of the rail. If the rigidity of a pair of fish-plates is less than that of the rail, the sleepers near the joint bear the major part of the load, and as a result, the joint sleepers will soon dip and make a rough-riding track. But it is difficult to design a strong fish-plate because the height of the plate is limited by the fishing height of the rail, especially when a rail lighter than 50 kgr./m. (100 lb./ yard) is employed.

On the Japanese Government Rys. the ratio of the sectional area of a pair of fish-plates to that of rails is as follows,

30 kgr./m. : 0.834,
37 kgr./m. : 0.859,
50 kgr./m. : 0.890 (flat fish-plates),
0.937 (angle fish-plates).

The area of a pair of fish-plates approaches that of the rail as the weight of the latter increases.

For rails heavier than 110 lb./yard (55 kgr./m.) used on the main lines of railways in the United States the value of this ratio is almost 1.00. The ratio for the 130 lb./yard rail of the Reading Co. amounts to 1.30, and that for the 100 lb./yard rail of the Northern Pacific Ry. is 1.17.

The fish-plates to be used for track carrying heavy loads at high speeds should be designed with as much sectional area as possible.

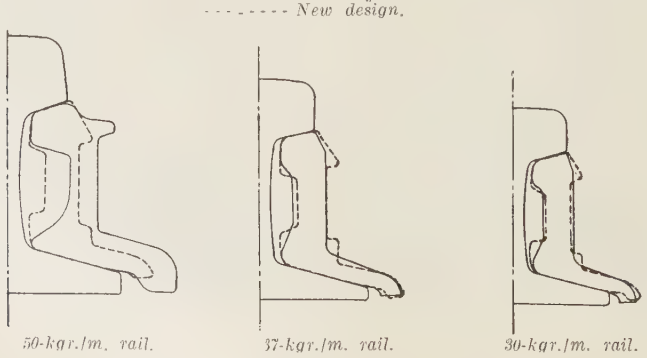
Although a pair of fish-plates should have the same sectional area as the rail, this does not mean that the rigidity of the fish-plates and the stresses therein should be the same as in the rail. It has been shown by investigations carried out on track actually in service that while the bending moment of fish-plates is only 40-60 % of that of rails under the same wheel load, the stresses in the fish-plates amount to more than double those in the rail. In an unsymmetrical type of fish-plate, such as an angle fish-plate, the maximum stress in the section is far greater than that in the symmetrical type of plate, owing to the inclination of the neutral axis from the horizontal.

It is necessary either to design the section of the fish-plates so that it will give the least possible stress under given loads, or to give the section of the fish-plates a symmetrical form so as to make the neutral axis horizontal.

Besides, the unsymmetrical fish-plate bends laterally under vertical loads, and gradually moves from its position, causing undue dipping of the rail joint.

On the Japanese Government Rys. the old fish-plates are to be replaced by newly designed plates as shown in Figure 24. The sectional area of the new plate for 50 kgr./m. rail is smaller than the old

Fig. 24. — Comparison of fish-plates of new and old designs.



type by about 17 %. Nevertheless, the maximum stress under vertical bending moment has been reduced by 4.3 % as compared with the old one because of its horizontal neutral axis.

The calculated stresses for both types are shown in Table 16, wherein Mv represents the bending moment at the joint, expressed in kgr./cm.

TABLE 16. — **Calculated stresses in fish-plates.**

Kinds of rail.	Kinds of fish-plate.	Sectional area in, cm^2.	Moment of inertia about the horizontal axis, in cm^4.	Inclination of the neutral axis to the horizontal.	Max. bending stress caused by free bending.
50 kgr./m.	Old.	30.1	300.4	24° 17'	0.03354 Mv
	New.	25.1	202.0	14° 52'	0.03211 Mv
	Increase in %.	—16.7	—32.8	—38.5	—4.3
37 kgr./m.	Old.	20.3	136.3	21° 54'	0.05384 Mv
	New.	20.1	135.9	20° 16'	0.04875 Mv
	Increase in %.	—0.8	—0.3	—7.0	—9.5
30 kgr./m.	Old.	15.9	89.5	19° 26'	0.07032 Mv
	New.	16.0	86.6	18° 36'	0.06572 Mv
	Increase in %.	0.6	—3.3	—4.3	—6.5

(II) Fish bolts.

The bending moment that occurs in the fish-plates is irrespective of their length; the adoption of longer fish-plates would, therefore, neither increase the rigidity of the joint nor decrease the pressure upon the sleepers near the joint. Increasing the length of the fish-plates is not as effective as increasing the sectional area of the plates, for the purpose of strengthening the rail joint. However, by the use of longer fish-plates, with six bolts, the effects of loosened bolts are somewhat diminished and the contact pressure between fish-plates and rails is less than in the case of shorter plates with four bolts. Furthermore, the play between the rail and fish-plates is less and the amount of unelastic yielding of the rail joint diminishes. Many Railways are using fish-plates 24″ to 27″ long, with four bolts, and their opinion is that the fish-plates, properly designed, with four bolts gives satisfactory results. Usually the diameter over the shank of fish bolts is 15/16″ (23.8 mm.) and that over the threads is 1″ (25.4 mm.). But several railways use bolts of 1 1/16″ to 1 1/8″ in diameter for rails heavier than 130 lb./yard (65 kgr./m.). A bolt 1″ (25.4 mm.) in diameter for the 100-lb./yard rail and 1 1/8″ (28.6 mm.) for the rail heavier than 130 lb./yard is thought sufficient to bear the tension required.

(III) Type of rail joint.

Almost every Railway Administration adopts the suspended joint as the standard for main line track, but several Railways in the United States adopt the supported one. The New York, Chicago and St. Louis RR. is the only one which has reported the use of the three-sleeper joint.

Joint sleepers sustain comparatively greater loads than intermediate sleepers. In the case of a supported joint, the sleeper just under the joint should bear the greater part of the load on the joint, and consequently is apt to yield. On the other hand, in the case of a suspended joint, the shock of the wheel at the rail joint shared between the adjacent joint sleepers and track maintenance is easier.

It is good practice to lay the two adjacent joint sleepers of a suspended joint as close as possible, in so far as tamping is not hindered.

We have also examined the possibility of the use of supported joints on a test track with a sleeper of especially large size, or two sleepers laid parallel and bolted to each other under the rail joint, besides a single sleeper of common size, but neither of these practices has proved satisfactory, it being impossible to properly pack these special joint sleepers.

Some railway adopts the random joint, i.e. the joint situated at random, without any regard to the relative position of sleepers. The random joint should be adopted only on track laid with heavy rails on closely spaced sleepers.

As to the system of rail joint to be used on main-line track, the opinion of Railway Administrations in the United States and Canada differs from that of Railways in other countries.

In the United States and Canada alternate (staggered) joints are recommended, while in other countries opposite joints are the standard.

The Japanese Government Rys. formerly employed the alternate joint in certain parts, especially on curves, but, they have now abandoned it, as the weak points of the rail joint are doubled by this system, and the maintenance labour as well as the oscillation of vehicles are increased.

On a track with alternate joints, a greater number of sleepers is required, for they are laid closer at every joint. The shocks and vibration caused to vehicles at rail joints would be doubled, too, in frequency. In the case of the opposite joint, the period of the free vertical oscillation (rolling and pitching) of vehicles will never set up resonance with the period of forced oscillation caused by the shock at rail joints, if the rails are longer than 17 m. (55′ 9 1/4″) as mentioned previously. When the alternate joint is adopted the rolling stock has a tendency to resonate with every kind of oscillation. The rolling motion, which is not marked with the opposite joint, is characteristic with the alternate joint. As the rolling stock oscillates more or less at every joint, in the case of the alternate joint, the frequency of such oscillations is obviously doubled. On the other hand, it should be borne in mind that the intensity of the force which causes the forced oscillation is less with the alternate joint than with the opposite joint.

The alternate joint should be adopted only on track where sleepers are closely spaced and the rail joint has sufficient rigidity, like the track of railways in the United States; otherwise the opposite joint is recommended.

(IV) **Joint gap.**

We have already referred to the width of gap to be left at the joint between long rails.

If the length of a rail is 10-12 m. (32′ 9 3/4″ to 39′ 4 1/2″) the joint gap may be fixed so as to make it zero at the highest temperature, as it is only 8 to 9.5 mm. (5/16″-3/8″) at the lowest temperature; such a width is not detrimental to track maintenance. Thus for the rails shorter than 12 m., it is not necessary to rely upon the compressive stress of the rail to absorb the expansion due to temperature rises.

In the United States, some Railways, such as the Delaware and Hudson, give no allowance for their rail joints, but as a rule, most Railways, according to the A. R. E. A. specification, lay the rails

with a maximum joint opening of 7/16″ (11.1 mm.) for the 45′ (13.716 m.) rails, 3/8″ (9.5 mm.) for 39′ (11.887-m.) rails and 5/16″ (7.9 mm.) for 33′ (10.058-m.) rails, and make it zero when the air temperature is 100° F. (37.8° C.), the width of the gap being suitably proportioned to the rail length and temperature in other cases.

On the Railways in Great Britain, the maximum gap width prescribed is 1/2″ (12.7 mm.), even for long rails up to 60′ (18.288 m.).

The expansion gap should be increased in proportion to the rail length and the maximum temperature, but as the displacement of the rail is constrained by the friction at the joints and between the ballast and sleepers, the amount of expansion or contraction is by far smaller than the value calculated by the formula ignoring constraints.

Therefore the gap width may be safely lessened without danger of rail deformation.

For rails shorter than 12 m., the maximum gap width of 8 mm. (5/16″) is supposed to be sufficient for ordinary conditions. In this case, the gap becomes zero at a certain temperature near the maximum; but as the axial force set up in the rail by a further temperature rise is slight, and the track can bear it safely, it is not necessary to take special precautions against buckling in the course of maintenance work.

10. Sleepers.

(I) Kinds and sizes of sleepers.

All Railway Administrations use wooden sleepers for their important main-line track, except the Great Western Ry. who has 500 000 steel sleepers with chairs in use. Most of the Railways in Asia use untreated sleepers, but in Europe and America treated sleepers are used exclusively, usually impregnated with creosote except on the Florida East Coast RR., the only railway in the United States to use untreated sleepers.

The standard dimensions adopted by the Japanese Government Rys. for sleepers is 20 × 14 × 213 cm. (8″ × 5 1/2″ × 7′ 0″). In the United States, sleepers used on main lines are 23 × 18 × 259 cm. (9″ × 7″ × 8′ 6″) in size; those used on the second-class lines or sidings are 20 cm. (8″) wide or 244 cm. (8′ 0″) long. On the other hand, Railways in Great Britain use broad and thin sleepers, such as 25 × 13 × 259 cm. (10″ × 5″ × 8′ 6″) for intermediate sleepers, and 31 × 13 × 259 cm. (12″ × 5″ × 8′ 6″) for joint sleepers. Broad-gauge (5′ 6″) railways in India use sleepers 274 cm. (9′ 0″) long.

The value of D (the rail pressure required to cause unit depression of the sleeper $= \frac{cb}{K\,[\eta_\rho]}$) calculated for various kinds of sleepers are shown in Table 17.

TABLE 17. — **Value of D** $= \frac{cb}{K\,[\eta_\rho]}$ **(C = 5 kgr./cm²).**

Size of sleeper.	D	Railways.
20 × 14 × 213 cm. *(8″ × 5 1/2″ × 7′ 0″)*	10 000 kgr.	Japanese Government Rys.
23 × 18 × 259 cm. *(9″ × 7″ × 8′ 6″)*	14 000 kgr.	Railways in U.S.A.
25 × 13 × 259 cm. *(10″ × 5″ × 8′ 6″)*	14 000 kgr.	Railways in Great Britain (intermediate sleepers).
31 × 13 × 259 cm. *(12″ × 5″ × 8′ 6″)*	16 800 kgr.	Ditto (joint sleepers).

The volume of the British standard intermediate sleeper is only 80 % of that of sleepers used in the United States, but it has nearly the same rigidity as the latter, and the rigidity of the joint sleeper is larger by 20 % though it has the same volume as the sleeper on the American railways.

It may be said that the sleeper used on the British railways is more economical, but, as a matter of fact, such a thin sleeper may be adopted only when a chair with a large bearing surface is used with coach-screws, because the durability of a thin sleeper is greatly affected by the degree of rail cut and the redriving of spikes or screws. On other railways where comparatively thin fish-plates and dog spikes are used, such a thin sleeper is inadequate.

(II) Number of sleepers laid in track

The number of sleepers per unit length, laid in the main track of railways in North America (including Canada) is different from those in the other countries, covered by this report.

Generally speaking, in North America, all Railways use 3 200 to 3 250 sleepers per mile (1 988 to 2 019 per km.) i.e., 24 sleepers per 39′ rail or 20 sleepers per 33′ rail, and at least 2 880 sleepers per mile (1 790 per km.). Therefore the spacing of the intermediate sleepers is 20″ (508 mm.) or less and is the same as those of the joint sleepers. If 1 988 sleepers 23 cm. (9″) wide and 259 cm. (8′ 6″) long are laid per kilometre, the sum of the bearing area is 1 177 m² per km. (20 400 sq. ft. per mile), and the rails are directly supported on sleepers for 46 % of the total rail length.

On the other hand, most Railways in Great Britain as a rule use 2 112 sleepers per mile (1 313 per km.), that is, 24 sleepers per 60′ rail. If 25 cm. (10″) wide and 259 cm. (8′ 6″) long intermediate sleepers are used, and 31 cm. (12″) wide joint sleepers, the supporting area is only 877 m² per km. (15 200 sq. ft. per mile) and 34 % of the total rail length is directly supported by sleepers. Thus the supported area in the tracks in Great Britain is about 75 % of that in the U. S. A.

The Japanese Government Rys. use 1 640 sleepers 20 cm. (8″) wide and 213 cm. (7′ 0″) long per kilometre (2 640 sleepers per mile), that is, 41 sleepers per 25-m. (82′ 1/4″) rail length. The supporting area is consequently 699 m² per km. (12 100 sq. ft. per mile), i.e. 33 % of the total rail length is directly supported by sleepers.

Such a remarkable difference between the sleepering in North America and that on other Continents is mainly due to the difference in axle loads. On the railways in North America, the maximum axle load is from 27 to 35 tons, and in other countries it is from 17 to 23 tons, the former being heavier by 60 %. The increased rail supporting area is therefore essential for main-line track in the United States.

The number of sleepers used per unit length of track should be determined taking into account the maximum axle loads carried by the track. The calculated depression of sleepers used by various railways is shown in the following table. The value for the different railways does not vary much if the weight of the rails, spacing of sleepers and the axle load of vehicles are taken into account.

—	Weight of rails, *kgr./m.*	Size of sleeper, *cm.*	Spacing of sleepers, *cm.*	Axle load, *tons.*	Rail pressure, *kgr.*	Depression of sleepers, *cm.*
Japan	50	20×14×213	70	16	2 800	0.28
Great Britain (intermediate sleepers). . . .	50	25×13×259	80	23	4 800	0.34
United States	65	23×18×259	50	36	4 500	0.32

The Japanese Government Railways have investigated the relation between track maintenance cost and the sleepering in order to determine the most profitable number of sleepers for their axle loads and train speeds. It has been found that it is most economical to use 15-16 sleepers per 33′ (10.018 m.) rail, i.e. 1 500 to 1 600 sleepers per km. (2 410 to 2 570 sleepers per mile), for their main line track.

Needless to say that, if a sufficient number of sleepers is indispensable to support safely the load of rolling stock, an excessive number of sleepers results in increased renewal and tamping costs, and becomes rather uneconomical. Therefore, the number of sleepers should be properly determined for each case, according to the axle loads and operating speeds.

When tamping is done by picks, the sleepers should be spaced so as not to obstruct the tamping work; clear space less than 300 mm. makes pick tamping difficult. When mechanical tampers are used, these drawbacks disappear.

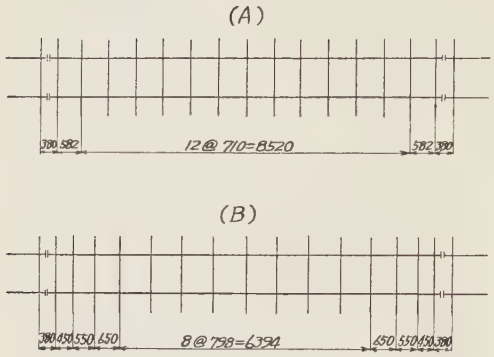
The sleepers should be so arranged along the length of the rail that the rigidity of the track be as uniform as possible throughout its whole length. As the joint is the weakest spot, the sleepers at and near it should be spaced closer than in the body of the rail so long as it does not hinder the tamping work, in order to prevent unevenness of the rail surface.

The Japanese Government Rys. are carrying out experiments with two kinds of sleeper arrangements, as shown in Figure 25. Type A has been the standard arrangement of sleepers hitherto in main line track; type B is a proposed spacing, in which several sleepers near the joint are spaced more closely. Records kept during the past three years show that type B is better than A as far as track labour is concerned. As regards gauge adjustment type B requires 15 % less labour, track alignment work

TABLE 18. — Tamping frequencies on the test tracks.

Number of sleeper.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tamping frequency during three years.	A	12.0	11.6	7.2	6.1	5.4	5.9	5.9	5.9	5.5	5.2	4.5	4.4	5.6	10.9	11.2
	B	10.3	10.3	6.9	5.1	5.1	5.8	6.3	6.7	6.4	6.3	5.9	5.8	7.9	10.2	10.3
Remarks.		joint sleeper	Running direction of trains. ⟶													joint sleeper

Fig. 25.



requires 1 % less, and 12 % less man-hours are required for surfacing the track. To sum up, the total man-hours required for the chief maintenance operations have been reduced to 89 % of those required with type A.

Tamping frequency during these three years on each track is shown in Table 18. It is comparatively less for the intermediate sleepers with the type A sleepering but the reverse occurs at and near the joint. It will be seen by this experiment that the rigidity of the track is more uniform with type B than with type A. The fact is that the amount of batter at the rail joint is smaller with type B than that with type A.

(III) Substitute sleepers.

Almost every railway uses wooden sleepers on its track for high-speed operation. Only a few railways use steel sleepers, rather as a trial. Reinforced concrete sleepers are not used in such track.

The Japanese Government Rys. are carrying out experiments with steel and reinforced concrete sleepers, but they have not yet found any ideal designs for use in main-line track carrying heavy loads at high speeds.

(IV) Kinds and numbers of dog spikes or coach-screws used.

The holding power of a coach-screw is remarkably higher than that of a dog (cut) spike. It has been proved by tests that the resistance to drawing out of the dog spike, 16 × 16 mm. (5/8″ × 5/8″) in section and 12 cm. (4 3/4″) in length is 1 300 kgr. (2 866 lb.) for a hard wood sleeper and 2 300 kgr. (5 070 lb.) for a soft wood sleeper; on the other hand the holding power of the coach-screw 24 mm. (15/16″) in diameter over the threads and 12 cm. (4 3/4″) in length is 3 000 and 4 600 kgr. (6 610 and 10 140 lb.) respectively. The holding power of a coach-screw is consequently about two to three times that of a dog spike.

Thus the coach-screw has the merit to hold the rail tightly and increase the life of sleepers, as it does not hurt the sleeper when it is redriven. Against this, a screw spike requires a longer time for renewal, and makes relaying quite complicated.

It is difficult to obtain full contact between the shank of a coach-screw and the edge of the rail foot, and there remains some clearance between them; in such a way the gauge is maintained only by the friction between the lower surface of the head of the coach-screw, and the rail foot. Therefore double shouldered bearing plates are used with coach-screws in order to increase the lateral rigidity of the track. Most railways using flat-bottomed rails adopt dog spikes; the number of spikes used per sleeper is four on straight track and six or eight on curves. But when more than six spikes are used per sleeper, the latter is liable to splitting or decay. The Japanese Government Rys. use dog spikes with flat bearing plates for 30 and 37 kgr./m. rails, and coach-screws with inclined tie-plates for 50 kgr./m. rails. Railways in Great Britain use the bull-headed rail, and need no spikes.

They use three coach screws or two bolts per chair, to clamp it to the sleeper, but these screws or bolts never receive direct lateral pressure from the rail base.

11. Bearing plates.

Almost every railway adopts some kind of bearing plate on main-track for high-speed operation. The bearing plate is indispensable to prevent rail cut and increase the life of the sleeper.

Decay of the sleeper may be checked by treatment, but the mechanical damage due to rail cut shortens its life and brings it into disuse before it becomes decayed, especially in the case of soft wood sleepers without bearing plates.

When bearing plates are not used at all, the lateral force acting upon a rail is resisted only by the dog spikes or coach-screws on one side of the rail, but when bearing plates are used, part of the lateral force is transferred to the spikes or screws at the other side of the rail foot by means of the bearing plates. As a result, the gauge of the track is maintained more easily. Rail braces in curved track may be abandoned when bearing plates are used.

Bearing plates must be designed so as to have sufficient bearing area to distribute the load on a large part of the surface of the sleeper. If it is too thin as compared with its length, it bends under the load, and the bearing pressure concentrates under the rail foot. Therefore the thickness of a tie-plate must be increased in proportion to its length, otherwise pronounced bending may take place under the maximum wheel load.

The length of bearing plates for flat-bottomed rails may be increased in proportion to the width of the rail foot, but the width of the bearing plates is restricted by that of the sleepers. In the United States where sleepers 9″ (23 cm.) wide are used, the width of bearing plates is usually 7 1/2″ (19 cm.), and the maximum width 8 1/2″ (21.6 cm.). The length is usually above 12″ (30.5 cm.) and the greatest is 15 1/2″ (39.4 cm.), such plates being used under the 152-lb./yard rails of the Pennsylvania Railroad. The bearing area of these plates is nearly twice as large as the contact area between the rail foot and the sleeper.

The Japanese Government Rys. use, under 50 kgr./m. rail, a bearing plate which is 16 cm. (6 5/16″) wide and 25.5 cm. (10″) long. That is 1.6 times the bearing area of the rail foot, but the result is good.

The chair used by British Railways is far heavier than the sole plate for the flat-bottomed rail. The Great Western Railway, the London and North Eastern Railway and the London, Midland and Scottish Railway use a chair having a base area of 14 1/2″ × 8″ (37 × 20 cm.) for 95-lb. bull-headed rails. The Great Western Railway and the London Midland and Scottish Railway use a special type having a base area of 14 1/2″ × 10″ (37 × 25 cm.) for the joint sleepers. The bearing pressure upon sleepers is thereby remarkably diminished.

The thickness of sole plates must be increased in proportion to their length. The A. R. E. A. has fixed the standard thickness of the 12″ (30.5 cm.) long bearing plate to 3/4″ (19 mm.) in the case of the flat bearing plate, and 1/2″-3/4″ (13-19 mm.) for the inclined plate (at the edge of the rail foot). The minimum thickness of the shorter plates is still 1/2″ (13 mm.).

The A. R. E. A. recommends ribs smaller than 1/4″ (6 mm.) on the bottom surface of bearing plates. Such ribbing is no doubt provided on single-shouldered bearing plates to prevent them from moving on the sleeper. Some Railways, however, adopt the flat-base bearing plate, as the ribs injure the sleeper and prevent close contact of the plate with the sleeper.

Bearing plates must be provided with

shouldering to transmit the lateral pressure acting upon the rail to all of the spikes or screws, whether they be inclined or not. Single-shouldered bearing plates have the merit that they may be used for several kinds of rail; which is, however, a rare case. When sole plates are used with coach-screws, they must be double-shouldered to maintain the gauge, because it is difficult to make the shank of a coach-screw come into direct contact with the edge of the rail foot.

12. **Anti-creepers.**

Rail creep depends not only upon the speed and weight of the train, and the gradient of the track, but upon the kinds of rail used and the properties of the roadbed. The light rail and soft roadbed favour rail creep remarkably. Rail creep disturbs the proper joint gap, and as a result, too large gaps occur in some cases, injure the rail ends, and cause undue oscillation of the rolling stock; in other cases the gaps close up and the track is apt to get deformed. Therefore creep must be limited as much as possible by the use of an adequate number of anti-creep devices. Many kinds of effective and durable anti-creepers have been designed and every railway adopts some type or other found most suitable for its track.

Anti-creepers properly speaking are not used with the bull-headed rails, but a steel wedge inserted between the rail and the chair instead of the wooden key. It has been the usual practice in the case of the flat-bottomed rail to notch the flange of the fish-plates and drive the dog spikes through the notch. The drawback of such practice is that the longitudinal force acting upon the rail concentrates at the joint and causes the failure of the rail end, and displacement or tilting of the joint sleepers may happen; therefore such practice is being abandoned. Of all the railways in the United States about half of them have retained notched fish-plates, while the others have not. In other countries, most railways do not notch the fish-plates. The proper number of anti-creepers to be used on one rail length should be decided according to the actual amount of creep found, taking into consideration the traffic, the gradient, and the weight of the rail. It is difficult to set a general rule as regards this number; however, most Railway Administrations install usually 6 to 8 anti-creepers on a 39′ (11.887 m.) rail in high-speed track. A few railways install 4 devices on the same rail length.

Rail creep is checked in proportion to the number of anti-creepers installed, but it cannot be prevented entirely, no matter how many anchoring devices are used.

The Japanese Government Rys. have made a series of experiments on the relation between the number of anti-creepers installed and the amount of rail creep. The following formula was obtained :

$$S = 0.76 \frac{12\,n}{l} S_0 \quad . \quad . \quad . \quad (a)$$

wherein

S = the amount of creep observed during a certain period when a rail is fitted with n anti-creep devices;

S_0 = the amount of creep observed during the same period when the rail is laid without anti-creepers;

l = rail length in metres;

n = number of anti-creepers per rail.

The formulæ derived from the preceding one for various rail lengths are as follows :

$$\left.\begin{array}{l} S = 0.69^n\ S_0 \text{ for } 9\text{-m. rails} \\ S = 0.72^n\ S_0 \text{ for } 10\text{-m. rails} \\ S = 0.76^n\ S_0 \text{ for } 12\text{-m. rails} \\ S = 0.85^n\ S_0 \text{ for } 20\text{-m. rails} \\ S = 0.87^n\ S_0 \text{ for } 25\text{-m. rails} \end{array}\right\} \quad (b)$$

As is shown by these formulæ, an increase in the number of anti-creepers reduces the amount of creep remarkably.

For example, when 4, 6, 8 and 10 anti-creepers are installed on a 12-m. rail, the amount of creep is reduced to 1/3, 1/5, 1/9 and 1/15 respectively.

It is more effective, for minimizing rail creep, to distribute the anti-creepers uniformly along the whole length of the rail than to concentrate them in some portion. We have observed a rail creep of 14 mm. per year when six anti-creepers were installed close together on a 12-m. rail, and only 11 mm. per year when they were scattered along the rail, or a reduction of 20 % as compared with the former case.

When notched fish-plates are used, wooden stakes are often driven at the side of joint sleepers to prevent their displacement, and such stakes are also effective when driven against sleepers with which anti-creepers come into contact. The Japanese Government Rys. have obtained empirically a formula to show the efficiency of stakes, their dimensions being 20 × 14 × 100 cm. (7 7/8″ × 5 1/2″ × 3′ 3 3/8″).

$$S = 0.89^{n'} S_0;$$

wherein

S = the amount of creep when wooden stakes are used;

S_0 = the amount of creep when stakes are not used;

$2n'$ = number of stakes used on a length of 10 m. (32′ 9 3/4″).

As is shown by the foregoing formulæ, wooden stakes are not as effective as anti-creepers; besides, a large stake driven in within the narrow space between sleepers much hinders maintenance work at the joint.

The Reading Co. fills the space between sleepers with broken-stone ballast up to 1 1/2″ (4 cm.) above the bottom surface of the sleeper. The resistance to the forces causing rail creep is developed by the friction between the ballast and the sleeper, or the cohesion of the ballast itself; it is a good practice therefore to use the broken stone or slag ballast and fill the space between sleepers up to their top surface.

13. Rail braces.

No railway has reported the adoption of rail braces on curved track. The Japanese Government Rys. formerly used wooden braces for the inner and outer rails of curves having radii smaller than 600 m. (30 ch.). But now the tie-plate has superseded the rail brace.

14. Ballast.

(I) Ballast section.

Every railway classifies its tracks into several classes and specifies different ballast sections for each class. The necessity of a sufficient depth of ballast to distribute the wheel load over a large area of the roadbed surface, and to prevent the undue depression of the track needs no comments. The depth of the ballast should be in keeping with the maximum loads and speeds.

The formula for finding the amount of pressure upon the formation, obtained by the American Special Committee on stresses in railway track is as follows :

$$p = \frac{16.8}{h^{1.25}} p_a .$$

where

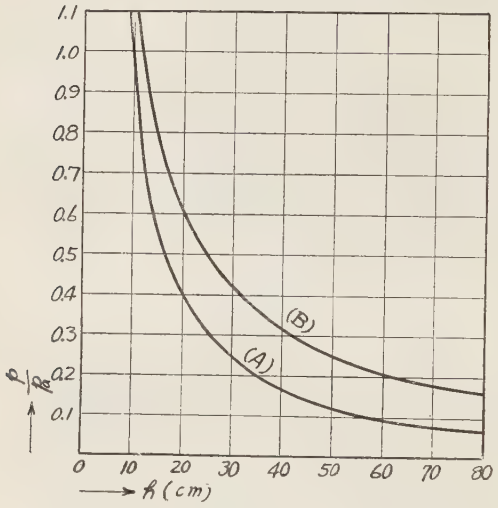
p = intensity of the vertical pressure at a point h inches below the bottom surface of a sleeper;

p_a = mean pressure intensity at the bottom surface of a sleeper.

The value of $\frac{p}{p_a}$ is shown by curve (A) in Figure 26. The Japanese Government Rys. adopt the following formula :

$$p_0 = \frac{h K^2}{\pi} \int_{-a}^{2l-a} p_x e^{-K^2 x^2} dx ,$$

Fig. 26.
Value of p/p_a.
(A) Special Committee of A. R. E. A.
(B) Japanese Government Railways.



wherein

$$K = \frac{1}{0.7\,h + 2.3}, \quad (h \text{ in cm.})$$

The ratio of p_a to the pressure $h = 0$, for any value of h, is shown by Curve (B) in the same figure.

It is apparent from these curves that the maximum pressure intensity upon the roadbed decreases remarkably as the depth of the ballast increases; for the depth of 25 cm. (10″) it decreases to 1/2-1/3 of the mean pressure intensity at the bottom surface of a sleeper.

On the main-line track of every railway in the United States, the depth of ballast under sleepers is usually 12″ (30.48 cm.), and the maximum depth is 14″ (35.56 cm.) or 15″ (38.1 cm.) for track carrying especially heavy trains.

The standard ballast section for first-class track, adopted by the A. R. E. A., consists of the top layer 12″ (30.48 cm.) deep under the sleeper, and the sub-ballast also 12″ (30.48 cm.) deep, under it. The sub-ballast is especially necessary for track in wet regions or cold districts, to favour drainage of the roadbed. The A. R. E. A. also recommends a ballast section of a total depth of 24″ (60.96 cm.), consisting of 18″ (45.72 cm.) or 14″ (35.56 cm.) sub-ballast and 6″ (15.24 cm.) or 10″ (25.40 cm.) top ballast respectively.

The New York Central Lines adopt a sub-ballast layer 15″ (38.10 cm.) deep under a 12″ (30.48-cm.) top layer. Such a large depth of ballast is not required by railways in countries other than the United States. As a rule, the depth is from 8″ (20.32 cm.) to 12″ (30.48 cm.) and does not exceed 20″ (50.8 cm.) as a whole, even when sub-ballast is used.

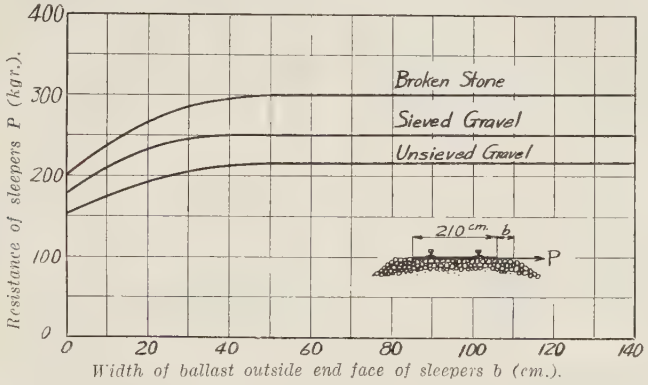
The width of the ballast section measured from the end of a sleeper to the shoulder of the section is 6″ (15.24 cm.) for most railways in the United States, and the maximum is 12″ (30.48 cm.) on the Pennsylvania Railroad.

Obviously the width is rather small as compared with its depth. In Great Britain, its Dominions and Colonies, the width is from 9″ (23.86 cm.) to 12″ (30.48 cm.) and usually 9 inches.

The resistance of the ballast against lateral displacement of sleepers is affected by the width of the ballast outside the end of the sleepers. It increases to some extent in proportion to its width, as shown in Figure 27, but attains its maximum value for a width of 40 to 45 cm. (15 3/4″ to 17 11/16″), and a further increase in width is by no means useful. The resistance of the track against lateral displacement is quite effective in maintaining the alignement of the track against the blows of high-speed trains, and preventing deformation due to a sudden temperature rise. Therefore, it is desirable to make the width of the ballast outside the end of the sleeper over 40 cm. (15 3/4″).

Ballasting up to the upper surface of the sleepers increases the stability of the track. In fact, this is usually done on most railways except in the United

Fig. 27. — Resistance of sleepers to lateral displacement.



States where the upper part of sleepers is exposed to a depth of 1/2″-2″ (12.7-50.8 mm.); it should be borne in mind, however, that the sleepers used are much thicker than those used in other countries.

The ballast at the shoulder will roll down in the course of a few days, if the end slope of the section is steeper than 1 : 1.75; it will not settle unless the slope is 1 : 2.5 to 1 : 3.0. The most suitable slope is 1 : 1.75 for broken stone and 1 : 2.0 for screened gravel ballast.

(II) Nature of ballast.

Broken stone and slag are better than any other materials. They are heavy, angular and non-absorptive, give good drainage, prevent weed growing, and will resist crushing. The size may be decided at will. Almost all railways adopt broken stone or slag as ballast on track carrying heavy loads at high speeds.

The Japanese Government Rys. use broken stone only on main lines. The cost of broken stone is higher than that of screened gravel by about 50 %. Besides, its production is limited, and it must be transported a long distance from its place of origin. Therefore it is not yet utilized generally, though it is to be used to a greater extent than at present. In some sections, screened gravel is replaced by broken stone only at the rail joint, for a length of 5-7 panels per joint, and satisfactory results have been obtained.

The Japanese Government Rys. have carried out experiments with several kinds of ballast and investigated the time required for maintenance work. It has been found that the labour required for track with broken stone is only 57-72 % of that with screened gravel, and even in the case where broken stone is used only at the rail joint, the maintenance work is decreased by nearly 19 %.

The resistance of broken stone against track displacement is larger than that of gravel as shown in Figure 27. It has been found by investigations that the amount of creep in the case of track with broken stone is less than with gravel ballast by about 20 %. The materials used as sub-ballast are cinders, sand, river gravel and stone; they are used to save on the cost of top-ballast, give good drainage and prevent mud from rising from the foundation. Most Railways in the United States use cinder, while those in Great Britain use stone pitching as sub-ballast; stones are often used for the sub-ballast material to prevent the track heaving by frosty weather.

(III) **Size of ballast.**

When broken stone or slag is used as ballast material, rather coarse grains are recommended for the stability of the track. But too coarse grains make handling in general and track surfacing work difficult, especially when mechanical tampers are employed.

For these reasons, the maximum size of grains used on all railways is less than 2 1/2″ (63.50 mm.). The lower limit of the grain is between 1″ (25.4 mm.) to 1/4″ (6.35 mm.), the most usual being 1/2″ (12.7 mm.).

The specification of the A. R. E. A. for broken stone ballast requires that 95 % of the total weight should pass a mesh 2 3/4″ (69.85 mm.) in diameter, and 95 % should remain on 3/4″ (19.1-mm.) mesh.

In Great Britain, all Railways use coarse grains : 4″ (10.16 cm.) to 8″ (20.32 cm.) in diameter as sub-ballast, and finer grain 2 1/2″ (6.35 cm.) to 1/2″ (1.27 cm.) as the top ballast for the track in cuttings. The London and North Eastern Railway fixes the size of ballast as follows :

40 % 1 3/4″-2 1/2″ (44.5-63.5 mm.);
45 % 1″ -1 3/4″ (25.4-44.5 mm.);
15 % 3/4″ -1″ (19.1-25.4 mm.),

and uses granite grain or flint pitching 1/4″ (6.35 cm.) in size, for packing under sleepers.

15. **Solid roadbed.**

No railway Administration adopts the solid roadbed to some extent in main-line track for high-speed operation of heavy loads, but in special sections where maintenance work is difficult, with the ordinary construction, such as long tunnels, highway crossings, and soft sub-soil, the adoption of a solid roadbed may be considered. In long tunnels, where track maintenance work is difficult, and unwholesome for the staff owing to smoke and cinders, a solid roadbed is built to minimize the time spent on maintenance work.

The New York Central Lines, the Japanese Government Rys. and some other Railways constructed track with solid roadbed in their large passenger terminals, but this is mainly for sanitary purposes, to facilitate cleaning of the track.

At highway crossings, turnouts, and special spots where the roadbed is quite soft, or where mud is pumped up over the surface of sleepers, a concrete slab is often placed upon the formation on which the ballast is laid in the usual way. This practice has proved satisfactory. The solid roadbed not only increases the cost of construction but becomes almost impossible to repair when the roadbed settles unequally, or the concrete surface fails under the loads.

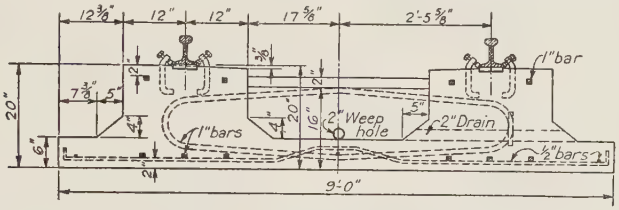
In 1926, the Pere Marquette Ry. began an experiment with the solid road bed on a section carrying medium traffic, and extending 1 326′ (404 m.). Rails were laid on a concrete slab 21″ (53.3 cm.) thick and 10′ (3.05 m.) wide, and fastened by C-shaped bolts buried in concrete. In 1929, a beam-type solid roadbed was designed as shown in Figure 28-A, and built adjacent to the former test track. With the improved type, the concrete beam is divided into sections about 19′ 6″ (5.94 m.) long, and is provided with rigid buttresses 6′ (1.83 m.) apart, to stiffen the beam. The beam has a depression on its upper surface; a treated wooden packing slightly narrower than the rail foot is laid in the depression and the rail is laid on this packing. The rail is fastened to the concrete by C-shaped bolts and screws.

When it becomes necessary to resurface the track, the concrete bed may be lifted by jacks and the proper amount of sand filled by compressed air between the lower surface of the beam and the formation. The results of the new design are said to be satisfactory. There are over 40 km. (25 miles) of solid roadbed on the lines of the Japanese Govern-

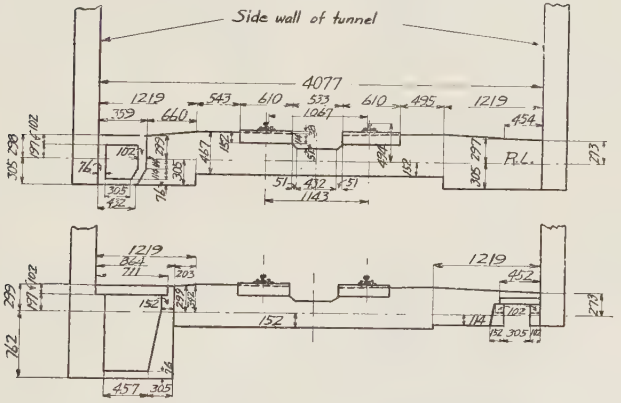
ment Rys. Most of them have been built to save maintenance work in long tunnels. The first solid roadbeds built were not satisfactory; various defects (design and carrying out) were subsequently discovered, the worst trouble being the decomposition of the concrete at the contact surface under the sleepers. At present some of them require more maintenance work than the ordinary ballasted track, besides causing violent oscillations to vehicles. Consequently,

Fig. 28.

(A) Cross section of new concrete road bed built in August, 1929. Pere Marquette RR.



(B) Section of concrete roadbed in the Shimizu tunnel. Japanese Government Railways.



several improved types have been designed and made use of in the actual track. Of all these designs the roadbed built in the Shimizu Tunnel, which was completed in 1931, is the most typical, and shows the best results. This tunnel has a total length of 9.7 km. (6 miles); the solid roadbed is located in its middle part for a length of 3.6 km. (2.24 miles). Its standard section is as shown in Figure 28-B. Treated wooden blocks 20.3 cm. (7 7/8″) wide, 15.2 cm. (6″) thick and 61 cm. (2′) long are buried in the concrete bed at a distance of 55.3 cm. (1′ 9 3/4″), c.t.c., (22 blocks per 12-m. rail) and the spacing of joint sleepers is diminished to 38 cm. (1′ 2 15/16″). The rails used weigh 50 kgr. per m. (100 lb. p. yd.) and the joints are suspended.

Standard double-shouldered bearing plates are used with 2 coach-screws per block. There remains a clearance of 2 mm. (5/64″) between the lower surface of the head of the coach-screw and the upper surface of the rail foot. This prevents the coach-screw from slackening, due to the upward pressure caused by the upheaving motion of the rail.

Semi-circular fillers are inserted between the head of coach-screws, spikes and sole plates, to fix them.

In some cases the concrete for the whole section is placed at the same time, but in other cases the lower layer is placed first up to 10 cm. (4″) below the bottom of the sleepers, and the upper layer after the rails and sleepers are set in their proper position. Either of these methods give satisfactory results if concrete of best quality is used and made compact by vibrators.

At the end of the solid roadbed a concrete slab about 3-5 m. (9′ 10″ to 16′ 5″) long is placed under the ballast to avoid a sudden change in elasticity.

The maintenance work on the solid roadbed section of the Shimizu Tunnel is only 40 % of that for the section with broken stone ballast. Cleaning of the roadbed surface takes up the greater part of the maintenance work, but as this section is electrified failure of the concrete surface is not so marked as in other tunnels.

The solid roadbed remained in quite good condition for 3 years after its construction, and is far superior in all respects to the ballasted section built at the same time. But after that period, the condition of the solid bed has grown gradually worse and come to resemble the ballasted section. The alignement and the gauge at the rail joints, and the contact between rail and sleeper have become rather inferior. Besides, the lateral oscillations of rolling stock are more violent than on the track with broken stone ballast.

Thus it has been proved that maintenance work is saved as expected, but the condition of track with a solid road bed has a tendency to become worse than that of track with ordinary ballast. Besides, repair work under traffic is almost impossible.

Consequently, the Japanese Government Rys. adopt the solid roadbed only on sections where the formation is hard, and is not liable to sinking.

In tunnels where smoke from the engines finds no exit, the sulphurous anhydride it contains dissolves in the leakage water and produces sulphuric acid, which desintegrates the concrete. Therefore careful investigations should be made before adopting the solid roadbed in tunnels.

Studies should be continued to find a proper design of solid roadbed for use on main-line tracks carrying heavy trains at high speeds.

16. Methods of reducing rail wear.

To reduce the wear of outer rails on curved track, two methods are adopted : the use of special steel rails, and the lubrication of the rails. The Illinois Central RR. was able to lengthen the life of rails to about 3 to 5 times that of ordinary carbon steel rails, by using austenitic manganese steel rails. Medium manganese steel rails (0.5-0.6 % of carbon and 1.5 % of manganese), used by the same railway, also proved satisfactory.

The London, Midland and Scottish Ry. is obtaining good results from special steel rails containing 1 % of chromium or 14 % of manganese for points and crossings on busy sections.

The London and North Eastern Ry. has experimented with various kinds of special rail steels, and is obtaining good results by the use of medium-manganese steel containing 0.90-1.20 % manganese and 0.50-0.60 % carbon, and the sorbitic rail made from it. Chrome-steel rails, containing 1 % of chrome have shown satisfactory results in tunnels.

The Japanese Government Rys. have used medium-manganese steel rails (0.45-0.55 % carbon, 1.3-1.5 % manganese) for the higher rail of curves on busy sections for years, and obtained good results from it. The amount of wear with these special steel rails, laid on sharp

curves where the life of the ordinary carbon rails is 27 months, was reduced to 1/5 of the latter, whereas the cost is estimated to be higher than that of ordinary rails, by only 50 %.

Manganese steel rails (1.13 % carbon, 11.98 % manganese) have also been tried on the most frequented electrified lines, where rail wear is heavy; wear of the manganese steel rails was only 1/7 that of the common rail. But the manganese steel rail is liable to fail when its heat treatment is inadequate; it is sensible to temperature changes; moreover the cost is several times that of the ordinary rail, and it is inferior to the medium manganese steel rail from an economic point of view. As to the sorbitic rail, the Japanese Government Rys. have found that its life on sharp curves is more than 3 times that of the ordinary rail.

The Japanese Government Rys. have co-operated with the Sumitomo Steel Works in an investigation into the wear of rails and tyres of various chemical compositions, laid on a special test section. This test track has a circular form and its radius is 24.40 m. (80′); the track gauge is 0.43 m. (1′ 4 5/16″) and 30 kgr./m. (60 lb.) p. yd. rails are used. On this track a four-wheeled railcar and a trailer are operated, each of them weighing two tons, and the wear of rails and tyres is measured quite accurately after the vehicles have been round the track from 8 000 to 120 000 times. First the carbon steel rails and tyres of different carbon contents were tested. Rails No. 1, No. 2 and No. 3 were made of open hearth steel, their carbon contents being 0.80, 0.53 and 0.35 % respectively, and No. 4 is a convertor-steel rail with 0.35 % of carbon.

The amount of wear after 8 000 rotations is shown in Table 19 and Figure 29. From these results, it is obvious that the wear of the tyre with largest carbon content is reduced, and not only the wear of the tyre itself, but also that of he rail, and the combined wear of tyres and rails is a minimum with a combination of hard tyres and soft rails. When using soft tyres, the wear of rails is markedly increased.

Fig. 29. — Amount of wear for various combinations of rail and tyre.
C — carbon content.

Test number.	Kind of tyre.		Kind of rail.	
	No.	C. %	No.	C. %
8	1	0.74	1	0.80
1			2	0.53
6			3	0.35
2			4	0.35
9	2	0.62	1	0.80
4			2	0.53
7			3	0.35
3			4	0.35
10	3	0.43—0.46	1	0.80
5		0.43	2	0.53
11		0.43—0.46	3	0.35
12		0.43—0.46	4	0.31—0.32

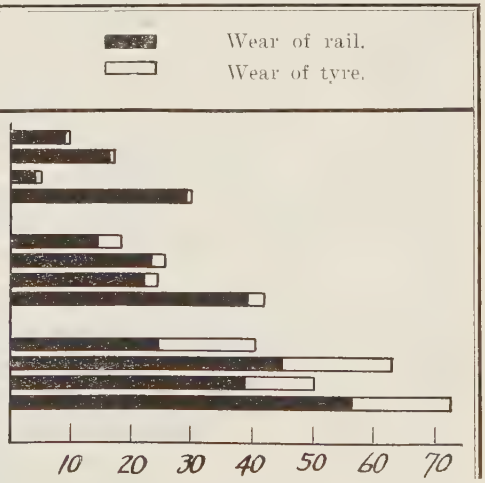


TABLE 19. — **Rail and tyre wear (after 8 000 rotations).**

Type of tyre.	Carbon content of tyre, in %.	Type of rail.	Carbon content of rail, in %.	Wear of tyre, in kgr.	Wear of rail, in kgr.	Combined wear of tyre and rail in kgr..	Ratio of wear of rail to that of tyre.
No. 1	0.74	No. 1.	0.80	0.994	8.25	9.244	8.30
»	»	No. 2.	0.53	0.860	16.50	17.36	20.20
»	»	No. 3.	0.35	0.215	4.40	4.615	20.42
»	»	No. 4.	0.35	1.600	28.75	30.35	18.00
No. 2.	0.62	No. 1.	0.80	3.925	14.00	17.925	3.57
»	»	No. 2.	0.53	2.750	23.50	26.25	8.55
»	»	No. 3.	0.35	2.547	22.40	24.947	8.80
»	»	No. 4.	0.35	3.250	39.25	42.50	12.10
No. 3.	0.43 0.46	No. 1.	0.80	16.778	24.00	40.778	1.43
»	0.43	No. 2.	0.53	18.525	44.75	63.275	2.41
»	0.43 0.46	No. 3.	0.35	12.59	38.20	50.790	3.04
»	0.43 0.46	No. 4.	0.31 0.32	16.151	56.45	72.601	3.50

The wear of rails containing 0.53 % carbon is the maximum with any kind of tyre. The wear of the convertor-steel rail is much higher than that of open-hearth steel. This investigation has shown that the rail wear may be reduced to a large extent by a proper combination of the carbon contents of tyres and rails.

Further experiments were made on the same test track with various combinations of rails made of high-carbon steel, sorbitic steel and manganese steel, and tyres made of high-carbon steel, sorbitic steel and chrome steel.

Table 20 shows their chemical composition; the amount of wear after 32 000 rotations is shown in Table 21 and Figure 30. The results may be summarized as follows :

(1) the wear of chrome steel tyres is the least of all for any kind of rail;

(2) tyre wear increases with the hardness of the rail;

(3) the rail wear decreases with the use of hard tyres;

(4) the amount of wear of the manganese-steel rail is about 1/3 that of the high-carbon steel rail, and is larger than the value observed in the actual track, where the manganese steel rail is used only on curves. This is probably due to the fact that the surface of the tyre tread becomes rough when the vehicle is operated on track where hard-manganese steel rails are used throughout, as compared with sections whereon most of the rail is made of ordinary soft carbon steel.

Almost every railway lubricates rails in sharp curves, to prevent rail and tyre wear, satisfactory results being obtained. For this purpose, various kinds of auto-

TABLE 20. — **Chemical composition of rail steel and tyre steel.**

Kind of steel.	Chemical composition, %.							Hardness number.
	C	Si	Mn	P	S	Cu	Cr	
				Tyres.				
High-carbon.	0.74	0.25	0.81	0.035	0.038	0.09	...	37
Sorbitic.	0.74	0.25	0.81	0.035	0.038	0.09	...	40
Chrome.	0.76	0.35	0.80	...	...	...	0.71	42
				Rails.				
High-carbon.	0.75	0.11	0.64	0.038	0.024	0.12	...	41
Sorbitic.	0.61	0.14	0.79	0.039	0.019	0.03	...	38
Manganese.	1.08	0.14	11.9	0.070	0.016	0.02	...	32

matic rail or flange lubricators have been devised.

The Japanese Government Rys. use a mixture of graphite and grease for coating the side of the outer rail head on sharp curves. Lubrication is done by hand and gives good economic results.

By lubricating the rail and tyre, the amount of wear is reduced to 1/5, and the running resistance is also remarkably decreased. Experiments made by the Japanese Government Rys. on the test track have shown that when the rail is lubricated, the mean speed of the railcar increases by 18 %. On the other hand, the power consumption decreased

Fig. 30. — Amount of wear for various combinations of rail and tyre.

H = High-carbon steel. Cr = Chrome steel.
S = Sorbitic steel. M = Manganese steel.

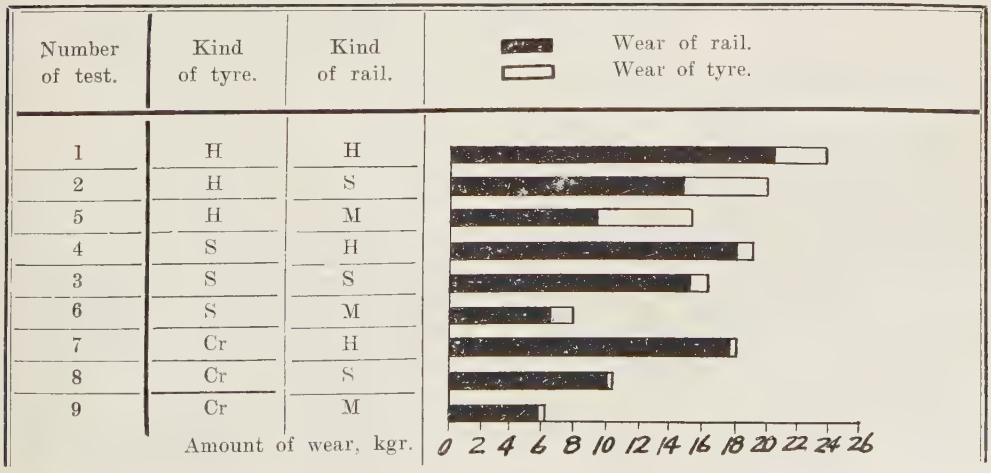


TABLE 21. — **Amount of rail wear and tyre wear (after 32 000 rotations).**

Kind of tyre steel.	Kind of rail steel.	Wear of tyre, in kgr.	Wear of rail, in kgr.	Combined wear of tyre and rail, in kgr.	Ratio of rail wear to tyre wear.
High carbon.	High carbon.	3.52	20.55	24.07	5.8
Sorbitic.	»	1.37	17.80	19.17	13.0
Chrome.	»	0.67	17.40	18.07	26.0
High carbon.	Sorbitic.	5.45	14.55	20.00	2.7
Sorbitic.	»	1.47	14.85	16.32	10.0
Chrome.	»	0.52	9.90	10.42	19.0
High carbon.	Manganese.	6.40	8.90	15.30	1.4
Sorbitic.	»	1.77	6.20	7.97	3.5
Chrome.	»	0.66	5.60	6.26	8.5

to 1/3. The amount of wear on lubricated rails is exceedingly small and rather difficult to measure, and tyre wear becomes about 1/80 of that recorded when the rail is not lubricated.

TABLE 22. — **Effect of lubrication.**

—	Amount of wear after 8 000 rotations.		
	Tyre.	Rail.	Combined.
Non-lubricated rail.	0.6240 kgr.	9.8000 kgr.	10.4240 kgr.
Lubricated rail	0.0075 kgr.	0.0010 kgr.	0.0085 kgr.

As is shown in Table 22, when the rail is lubricated throughout, the wheel tread surface becomes extraordinarily smooth and rail wear is stopped, but on the actual track, where oil is applied only on curved sections, such good results are not expected. To reduce rail wear it is most desirable to lubricate the whole section so long as it does not hinder the starting and braking of trains.

Formerly the Japanese Government Rys. used guard rails on the inner side of the low rail of sharp curves to prevent the wheels from running hard against the outer rail. However, the use of guard rails is uneconomical as they must be renewed frequently and are detrimental as regards maintaining uniform curvature of the track. Therefore they have been removed recently from the track, and replaced by the use of rail lubrication or medium manganese steel rails.

17. Guard rails on curves.

It is the usual practice in Great Bri-

tain, its Dominions and Colonies to lay the guard rail on the gauge side of running rails on bridges and sharp curves in order to protect the vehicles against derailment or prevent the derailed vehicles running far out from the track. In general, the guard rail is laid with its head at the same level as the running rail on the inner side of the lower rail on curves sharper than 10 ch. (201 m.) or 8° (R = 218 m.), but the Ceylon Government Ry. uses it on every curve sharper than 30 ch. (603 m.). The Buenos Aires and Pacific uses it on curves of less than 500 m. (25 ch.) radius. In the United States, the New York Central Lines and the Norfolk and Western Ry. report the use of guard rails on curves.

The minimum amount of flange-way of curve guard rails varies from 1 3/4″ (44.5 mm.) to 2 1/2″ (63.5 mm.) and the gauge widening corresponding to the radius of the curve should be added to the above value.

The Japanese Government Rys. use guard rails on every curve of less than 300 m. (15 ch.) radius in first-class lines. They are laid on the inner side of either lower or higher rail or, in some cases, of both rails. Our experiments so far, show that the possibilities of vehicles derailing to the outside or inside of curves are nearly the same. Therefore, the guard rail should be laid on either side so as to reduce to a minimum the danger of vehicles becoming derailed.

* * *

PART II.

Methods of modernising old track for heavy loads at high speeds.

Answers of Railways with regard to this Part are summarized in Table 24.

1. Purpose of track improvement.

Generally speaking, old tracks have been constructed for light loads moving at low speeds, with steep gradients, sharp curves and light track materials; accordingly, they cannot take modern heavy loads at high speeds. Nowadays, a locomotive weighing 507 tons, with a maximum axle load of 35.6 tons, is operated at a speed higher than 120 km. (75 miles) an hour.

Railways in Great Britain and the United States allow a maximum speed of 144 km. (90 miles) per hour, and even on narrow-gauge railways the maximum authorized speed is 95 km (59 miles) per hour. For some time almost all Railways have been operating long-distance non-stop high-speed trains over their main lines, and many of them exceed an average speed of 100 km. (62 miles) per hour.

In order to operate heavy loads at such high speeds, the following points should be given consideration as regards the construction and maintenance of the track to ensure safe operation of trains.

(1) Safety of the trains against derailment and overturning;

(2) Strength of the track to bear the impact caused by high-speed operation of heavy loads;

(3) Sufficient strength to maintain the track in perfect condition.

2. Safety of the trains as regards derailment and overturning.

Sharp curves offer the greatest danger to high-speed operation; if a train is operated at a higher speed than permissible over such a curve, the result is overturning or derailment of the vehicles. When a sharp curve exists on the level or down gradient several minutes will be wasted in retardation and acceleration; not only will time be lost but fuel consumption will be much increased as well. Moreover, excessive acceleration and retardation of trains is harmful to riding conditions.

Therefore curves should be avoided

as far as possible on track for high-speed operation, and when they are inevitable, they must be as flat as possible. The minimum radius of curves on main lines is generally above 600 m. (30 chains) except in mountainous districts. The maximum permissible speed over curves 600 m. in radius is from 88.5 to 113 km. (55 to 70 miles) per hour and the theoretical amounts of superelevation for these speeds are 148 mm. (5.8″) and 240 mm. (9.5″) respectively. As a matter of fact, theoretical superelevation for the maximum permissible speed cannot be provided on such a curve. It may be said that a radius of 600 m. is too small for track carrying modern high-speed trains.

The New York, Chicago and St. Louis RR. is improving the curves of 3° (R = 582 m.) into 1° (R = 1 746 m.) or 1° 30′ (R = 1 164 m.) and the Atchison, Topeka and Santa Fe Ry. is converting its curves into 1° or 1° 30′ at least. The Delaware and Hudson is improving its curves into 3° at least and 1° if possible.

At the entrance and exit of bridges or platforms where the distance between parallel tracks is to be widened, short reverse curves are often inserted. The radii of these curves must be as large as possible; otherwise, the riding of high-speed trains would suffer.

The length of a curved track should be at least that of the transition curve. The Japanese Government Rys. prescribe the length of the transition curve to be less than 3/4 of that of the original curve. For example, if the curve is provided with 40 mm. (1.58″) superelevation, with a transition curve 1 000 times as long as the amount of the superelevation, the original curve must be longer than $0.04 \times 1\,000 \times 4/3 = 53.3$ m. (175′); if the intersection angle of tangents is 1°, the radius of the curve must be above 3 055 m. (10 023′). For such a short curve, a radius larger than 3 000 m. (9 843′) is often adopted.

The superelevation of a curve should be run off on the whole length of the transition curve, the length of which should be increased in proportion to the operating train speed. The angular velocity of the tilting motion of vehicles at the ends of the transition curve increases in proportion to the operating speed. On some old tracks, there is no transition curve and the superelevation is run off in the straight section. In this case, on the approach section to the curve, the vehicle bodies are inclined to the inside of the curve, and at the point of the curve the direction of the inclination is suddenly changed to the outside, and vice versa, on its exit.

Therefore, in order to modernise the old tracks, all the curves should be transitioned, usually in a length at least 1 000 times the amount of the superelevation given. Some Railway Administrations reduce the latter on a distance longer than 1 500 times the superelevation.

The oscillation of vehicles at the end of reverse curves is more violent than at the ends of a simple curve. For this reason it is necessary to increase sufficiently both the radius and the length of the superelevation ramp in the case of reverse curves, and insert an adequate straight length between the end and beginning of adjacent transition curves.

When points and crossings are laid in curves sufficient superelevation cannot be given, but the switches are usually laid level, especially so with a switch curve branching off to the outside of a curve, and severe speed restrictions must be laid down in such case. Therefore points or crossings should not be laid in curves where train operate at high speeds, or otherwise smooth riding is beyond expectation.

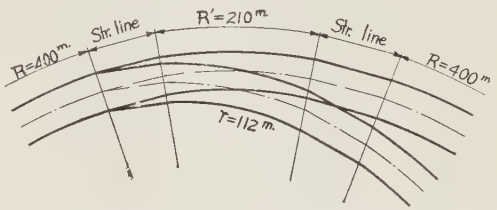
The Japanese Government Rys. use special sole plates under the frog (V piece) of double-curve points to give a certain amount of superelevation to each of the lead curves, and this has

proved effective for minimizing oscillation of vehicles.

When the straight type of tongue rail or crossing is used on curved track, not only the radius of the branch line but also the radius of the main line adjoining the switch becomes small especially when a crossing (frog) of small number is used, and the operating speed is to be severely restricted.

For example, if a No. 12 standard straight type crossing of the Japanese Government Rys. is laid on the inside of a curve of 400-m. (20 ch.) radius, the radius of the main line is reduced to 210 m. (10 1/2 ch.) and that of the branch line becomes 112 m. (5.5 ch.). In such a case, therefore, a curved switch is recommended (fig. 31).

Fig. 31.



The following table shows the comparison between switches of the straight type and the curved switches adopted by the Japanese Government Rys. as their standard.

TABLE 23. — **Radii of curves when switches are laid in curved tracks.**

Crossing (frog) number.	Original radius of the main curve, (m.).	Straight type switch.		Curved type switch.	
		Radius of the main line, (m.).	Radius of the switch curve, (m.).	Radius of the main line, (m.).	Radius of the switch curve, (m.).
No. 10.	300	154	78	300	128
	400	205	90	400	144
	500	257	98	500	153
	600	308	105	600	161
No. 12.	300	158	95	300	155
	400	210	112	400	178
	500	263	125	500	195
	600	316	136	600	207

As can be seen from Table 23, when a curved type switch is used in the curved track, the radius of the main line remains unchanged and that of the lead curve is by far greater than with a straight type switch.

The Japanese Government Rys. have relocated many of their curves accompanying switches in order to increase the radii and abolish speed restrictions. This necessitates removing the switches to the straight section and usually entails heavy expenses. But of late, they attain the same object at comparatively small cost — only 1/2 to 1/5 of the former cost — by utilizing curved tongues and crossings.

The same results may be obtained in the case of diamond crossings in curved track. By the adoption of a movable curved crossing, the curvature of the main line remains unaffected and the

riding conditions may be markedly improved.

Even on the straight line, the rolling stock oscillates vertically and laterally when passing over points and crossings. If a number of points and crossings are laid in succession and the vehicles run over them at a speed at which the period of their natural oscillation coincides with the period of the forced oscillation caused at points and crossings, the oscillations would be amplified by resonance until they cause derailment of the vehicles. Resonance is most liable to be set up in wagons. Therefore, care should be taken to minimize the number of switches as far as possible on main lines carrying high-speed trains, even though they were straight, because vehicles cannot be permitted to pass over a series of switches at the same maximum speed as on the open track.

3. Strength of the track to bear the impact caused by high-speed operation of heavy loads.

The construction of the track should always be such that it can safely bear the weight of vehicles operated; in other words, the sum of the static stress and the impact caused by rolling stock should never exceed the maximum strength of the track materials.

The dynamic augment of stress due to train speed varies to a large extent according to the design of engines, especially the counterbalancing of driving wheels. But in the case of ordinary steam locomotives the impact (maximum stress) on the rail may be assumed to grow by 1 % for each increase in speed of 1 km. (0.6 mile) an hour.

The use of heavy rails is most essential for the construction of track carrying heavy loads at high speeds. The combined stresses due to vertical and lateral loads, including the impact, should never exceed the fatigue limit of the rail. The light rail is apt to fail, its fish-plates break and its rail ends soon be battered, resulting in increased oscillation of vehicles and high track maintenance expenses.

The rail should have sufficient rigidity to distribute the weight of the rolling stock over as large an area as possible of the roadbed through the medium of the sleepers.

The rigidity of the rail is more important than its tensile strength, from the economic point of view. In the United States where very heavy axle loads are met with, rails from 110 to 152 lb./yard (50-76 kgr./m.) are most commonly used, and in the other countries 100 lb./yard (50 kgr./m.) rails are generally used on main lines.

The design of strong, stiff fish-plates is easier in the case of a heavy rail as there is ample space between its head and foot, which is effective in reducing rail end batter.

The use of long rails is also effective in saving maintenance costs, as the number of rail joints is reduced. While most Railways in the United States have replaced the old 33′ (10.058 m.) rails by the standard 39′ (11.889 m.) rail and use 66′ (20.117 m.) rails at level crossings, Railways in Great Britain adopt as their standard the 60′ rail and use a 90′ rail tentatively. Recently the Japanese Government Rys. have increased the standard length of the 30 kgr./m. rail from 10.058 m. to 20 m., and that of the 37 and 50 kgr./m. rails from 10.058 m. and 12 m. to 25 m. The standard lengths are thus more than twice the former. Various investigations carried out both theoretically and experimentally on the test track with regard to the buckling of rails contributed to the adoption of these longer lengths.

On sharp curves where rails are worn rapidly, lubrication of the outer rail by means of mechanical or manual means is resorted to in order to reduce such wear, satisfactory results being obtained. The use of medium manganese-steel or

sorbitic-steel rails also proves economical at special locations.

The maximum stresses in fish-plates differ to a large extent according to their design, even if they have the same sectional area. With the unsymmetrical type of fish-plates the neutral axis of the section under the vertical bending moment makes a certain inclination with the horizontal, and the maximum stress in the section increases in proportion to the angle of inclination of the neutral axis. Therefore most of the fish-plates recently designed take a symmetrical form with regard to the horizontal axis, a mass of metal being added to the inner sides of the top and base of the plates.

In order to obtain a rigid construction of the track, a sufficient number of sleepers of the proper size should be used. The spacing of sleepers should be adjusted to give uniform rigidity, and near the joints sleepers must be spaced as closely as tamping allows. But when the life of sleepers is short, renewal work is frequent and the roadbed is often disturbed, which means increased maintenance costs. Consequently sleepers of good resistance to decay and mechanical wear are valuable. The sole plate or chair is indispensable on track carrying heavy loads at high speeds, to resist the lateral thrust of the rolling stock and lengthen the life of sleepers by preventing rail cut, and there is a tendency to increase the thickness and base area of sole plates. If sole plates are made too thin, they bend under the load and are unable to distribute the wheel load over a large sleeper area.

Cast iron chairs used in Great Britain are most suitable to hold the double-headed rail, and when they are used, the thickness of sleepers may be lessened.

Most Railways in the United States adopt single-shouldered inclined sole plates with dog spikes. Coach-screws are superior to dog spikes as regards holding power, but they should always be used with double-shouldered sole plates. The pressure intensity upon the roadbed is decreased rapidly as the thickness of the ballast is increased. The thickness of the ballast under sleepers on track for heavy loads moving at high speeds must be 200 mm. (8″) at least and in general 300 mm. (12″) is desirable. In the case of the wet roadbed, especially in the cuttings, a sub-layer of sand or cinder 200 to 300 mm. thick placed under the stone ballast gives satisfactory results.

The ballast is not only used for distributing the vertical load over the roadbed, but plays an important part in resisting lateral displacement of the track. The high-speed train exerts an intense lateral thrust upon the rail especially on curves. If the resistance of the ballast is not sufficient, the correct alignement of the track cannot be maintained, and unpleasant riding conditions as well as unequal rail wear are the result.

The resistance of sleepers to lateral displacement depends upon the width of the ballast measured from the end surface of sleepers to the crest of the ballast. The ideal width of the ballast outside the end surface of the sleeper is 400 to 450 mm. (16 to 18″), as the maximum value of resistance against lateral displacement is attained thereby. But the resistance to lateral displacement of the track depends not only on the width of the ballast placed outside the sleepers, but also on the friction between the ballast and both sides of the sleepers, the value of the resistance due to the latter cause being almost the same as that due to the former cause. It is most desirable to fill the ballast up to the top surface of the sleepers, if possible.

When long rails are laid with relatively small expansion gaps, the latter would close up if temperature rose to a certain extent. If the frictional resistance between ballast and sleepers is insufficient, the rail may buckle and endanger safe train operation.

There is a close relation between the quality of the ballast and the quantity

TABLE 24. — Metho

RAILWAYS.	1	2	3	4		5	
	Improvement of sharp curves.	Improvement of transition curves.	Improvement of steep gradients.	Weight of rails.		Length of rails.	
				Old.	New.	Old.	New.
Japan and China.							
Japanese Government . . .	Yes, curves accompanying switches are improved.	Yes.	Yes, on the sections where pusher engines are used.	30 kgr./m. and 37 kgr./m.	37 kgr./m. and 50 kgr./m.	30-kgr. rail : 10.058 m. 37 and 50-kgr. rail : 10.058 m. or 12.000 m.	20 m. 25 m.
Chosen, Government-General.	...	Yes.	...	...	...	...	...
Chinese Rys.	...	Yes.	...	Heavier rails.		...	...
Great Britain, Dominions and Colonies.							
London, Midland and Scottish	...	...	No.	...	...	..	...
London and North Eastern .	...	Yes.	No.	...	...	...	...
Great Western	Yes.	Yes.	...	...	...	...	...
Southern	...	...	Yes, partially where necessary.	...	95 and 100 lb./yd.	...	...
Great Northern	...	...	Yes.	...	...	...	...
Canadian National	...	Yes.	Yes.	Heavier rails.		10.058 m. (33')	11.887 m (39')
North Western (India) . . .	Yes.	Yes.	Yes.	...	...	...	...
Great Indian Peninsula . .	...	Yes.	Yes.	...	...	...	...
East Indian	...	Yes.	...	...	...	...	12.801 m (42')
Madras and Southern Mahratta.	...	Yes.	...	...	...	...	12.192 m (40'
Bengal Nagpur	...	Yes.	Yes.	...	...	...	13.716 m (45')
Burma Rys.	...	...	...	...	...	...	...
New Zealand Government . .	...	Yes.	...	...	34.7 kgr. (70 lb.). 49.6 kgr. (100 lb.). (in tunnels).	...	Welde long ra tentative
New South Wales Government.	...	Yes, curves sharper than R = 1 608 m. (80 ch.).	...	39.7 kgr. (80 lb.).	49.6 kgr. (100 lb.).	...	68.6 m (225') Tentativ 549 m (1 800"
Sudan Government	...	Yes.	...	...	...	...	...
Nigerian Ry.	Yes, curves sharper than R = 291 m. (19.5 ch.) (6°).	Yes.	Yes, gradients steeper than 1 in 81.	...	...	9.144 m. (30')	12.192 m (40')

of modernising old track.

6		7	8	9	10	11	12	13
Number of sleepers laid.		Use of bearing plates.	Use of anti-creepers.	Use of rail braces.	Enlargement of ballast section.	Improvement of ballast materials.	Improvement of switches.	Miscellaneous means.
Formerly.	Now.							
1 500/km.	1 640/km.	Yes.	Yes.	Yes, but being replaced by bearing plates.	...	Broken stone instead of sieved gravel.	Switches of larger crossing number. Specially rolled tongues. Movable crossings. Continuous-rail crossings.	...
...	...	...	...	...	...	...	Switches of larger crossing (frog) number.	...
...	...	...	Yes.	...	...	...	...	...
...	...	...	...	...	Yes.	. .	...	...
...	...	...	Yes.	...	...	. .	...	...
...	...	...	...	...	...	. .	...	...
...	...	...	Yes.	. .	...	. .	Yes.	...
...	...	...	...	...	...	...	Yes.	...
...	...	Yes.	Yes.	...	Yes.	...	...	...
...	...	Yes.	Yes.	...	Yes.	...	...	...
...	...	...	Yes.	...	Increase in depth.	Broken stone used.	. .	...
...	...	Yes, with soft sleepers.	Yes.	...	Yes.	...	...	...
...	...	Yes.	Yes.	. .	...	Broken stone used.	...	...
...	...	Yes.	Yes.	...	Yes.	38.1 mm. (*1 1/2"*)	...	...
...	...	...	Yes.	...	...	...	...	...
...	...	Yes.	Yes.	...	...	...	...	...
...	...	Yes, on curves R < 400 m. (*20 ch.*).	Yes.	...	Yes.	Yes.	...	...
...	...	Yes.	Yes.	. .	...	...	...	...
...	...	...	Yes.	...	Yes.	...	...	...

TABLE 24. — Methods

RAILWAYS.	1	2	3	4		5	
	Improvement of sharp curves.	Improvement of transition curves.	Improvement of steep gradients.	Weight of rails.		Length of rails.	
				Old.	New.	Old.	New
U. S. A.							
New York, Chicago and St. Louis.	Yes.	Yes.	Yes.	42.1 kgr. (*85 lb.*).	55.5 kgr. (*112 lb.*).	10.058 m. (*33'*)	11.887 (*39'*
Reading Co.	Yes.	Yes.	Yes.	...	...	10.058 m. (*33'*)	11.887 (*39'*
Atchison, Topeka and Santa Fe.	Yes.	Yes.	Yes.	...	...	...	...
Baltimore and Ohio	Yes.	Yes.	Yes.	...	...	10.058 m. (*33'*)	11.887 (*39'*
Chicago, Burlington and Quincy.	...	Yes.	...	...	...	...	...
Norfolk and Western . . .	Yes.	Yes.	...	...	64.9 kgr. (*131 lb.*).	10.058 m. (*33'*)	11.887 (*39'*
Delaware and Hudson . . .	1 746 m. (1o) if possible, and 582 m.(3o) at least.	Yes.	Flatten down gradients to 5 o/oo — 3 o/oo (1/200 — 1/334)	...	64.9 kgr. (*131 lb.*).	...	...
Chesapeake and Ohio . . .	...	...	Yes.	...	64.9 kgr. (*131 lb.*).	...	20.117 (*69' 3* highw crossings turnou
Illinois Central	...	Yes.	...	44.6 kgr. (*90 lb.*).	55.4 kgr. (*112 lb.*).	...	...
Great Northern	Curves sharper than R = 582 m. (3o).	Yes.	Maximum gradients 6 o/oo.	...	...	...	...
Atlantic Coast Line	...	Yes.	Yes.	...	...	...	...
Florida East Coast	Yes.	Yes.	Yes.	...	...	...	...
Chicago, Rock Island and Pacific.	Yes.	Yes.	Yes.	...	...	...	...
Pere Marquette	...	...	...	...	...	...	...
Pennsylvania	...	Yes.	...	...	...	...	...
Other Countries.							
Entre Rios	...	...	Yes.	...	37.2 kgr. (*75 lb.*).	...	...
Central Cordoba	...	...	...	24.8 kgr. (*50 lb.*).	34.7 kgr. (*70 lb.*).	9.144 m. (*30'*)	12.192 (*40'*
Paulista	...	Yes.	Yes.	44.6 kg. (*90 lb.*).	54.5 kgr. (*110 lb.*).	12 m. (*39' 4 3/8"*).	13.72 (*45'*

Note. — No particulars coming within the scope of Table 24 have been supplied by the following Railw way Systen (U. S. A.); Northern Pacific; New York, New Haven and Hartford; New York Central Lin

nodernising old track. (*Contd*).

6		7	8	9	10	11	12	13
Number of sleepers laid.		Use of bearing plates.	Use of anti-creepers.	Use of rail braces.	Enlargement of ballast section.	Improvement of ballast materials.	Improvement of switches.	Miscellaneous means.
Formerly.	Now.							
1 988/km. (*3 200/mile*).	2 019/km. (*3 250/mile*).	Yes.	Yes.	Rarely.	...	Broken stone and slag ballasts adopted.	Manganese steel and heat-treated steel used for switches.	Switches repaired by electric arc welding.
...	...	Yes.	Yes.	Adopts new type.	Yes.	...	...	...
...	...	Yes.	...	...	...	...	...	...
1 790/km. (*2 880/mile*).	1 850/km. (*2 977/mile*).	Yes.	Yes.	...	...	...	...	...
...	...	Yes.	Yes.	...	...	...	...	...
Increased where necessary.		Yes.	Yes.	...	Improved the standard section.	Broken stone used.	Yes.	...
...	1 790/km. (*2 880/mile*).	Yes.	Yes.	Only in switches.	Yes.	Broken stone used.	Use manganese steel.	...
...	...	Improved bearing plates.	6 per rail length.	Only in switches.	Yes	...	Heavy rails. Spring switches.	...
...	...	Yes.	Yes.	No.	Yes	...	...	...
...	...	Yes, improved type adopted.	8—12 per rail.	Only in switches.	Yes.	Washed gravel used.	...	Increase length of sleepers.
...	...	Yes.	Yes.	...	Yes.	...	...	...
...	...	Yes.	Yes.	...	...	...	...	...
...	...	Yes.	Yes.	...	Yes.	...	...	...
...	...	Yes.	Yes.	...	...	...	Manganese steel used.	...
...	...	Yes.	Yes.	...	Yes.	...	...	...
...	...	...	...	...	...	..	...	...
777/km. (*1 250/mile*).	932/km. (*1 500/mile*).	...	...	...	Broken stone or gravel used.	...	70-lb. type.	..
1 617/km. (*2 440/mile*).	1 603/km. (*2 580/mile*).	New type adopted.	...	...	Yes.	...	...	..

Administrations: Great Southern Railways (Ireland); Canadian Pacific; Ceylon Government; Southern Rail-Pennsylvania Railroad; Missouri Pacific; Delaware, Lackawanna and Western; Buenos Ayres and Pacific.

used on the one hand, and the strength of the track on the other. Broken stone and slag give better results than any other ballast material, and most railways adopt either of them on track for heavy loads moving at high speeds.

The Japanese Government Railways have hitherto used screened gravel for main-line track, but of late they are replacing it by broken stone on the principal lines. The practice adopted of placing broken-stone ballast at rail joints only has given good results.

The so-called solid roadbed with which the sleeper rests directly upon a continuous slab is not generally adopted on main-line track. This is because the sleeper laid on a solid roadbed bears almost all of the axle load of vehicles, which results in the breakage of the concrete under it; moreover it is practically impossible to repair the broken concrete bed under traffic. But in a long tunnel, where maintenance work is difficult, the use of a permanent bed may be considered. A well-designed permanent bed has a long life even in tunnels, and the reduction in maintenance costs is estimated to be about 50 % as compared to the ordinary ballasted track. On electrified lines, a permanent roadbed is particularly advisable, as there is no fear of corrosion of the concrete by acid fumes.

In the case of soft roadbeds, whereon the vertical or lateral oscillations of vehicles are violent, and the maintenance work is difficult, or in clayish cuts where the clay is sucked up into the ballast by the pumping action of sleepers

Fig. 32. — Concrete roadbed.

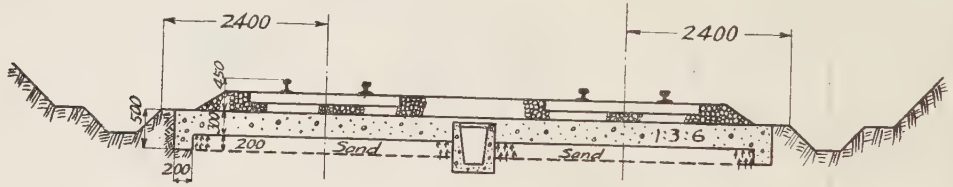
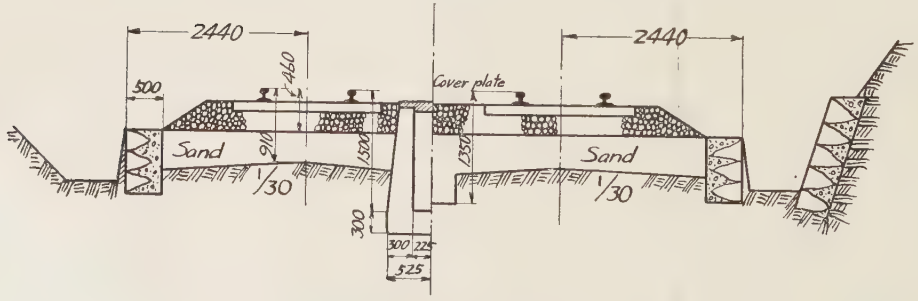


Fig. 33. — Roadbed with layer of sand.



under loads, a reinforced or plain concrete slab about 300 mm. (12″) thick may be laid beneath the ballast as shown in Figure 32. Where the pumping action is not so severe, the method which consists in removing the upper layer of the

formation for about 300 mm. (12″) and filling the place with sand or cinders as shown in Figure 33 may be adopted.

It is the usual practice to lay coarse stone ballast as a sub-layer to improve the drainage of the track, when the ballast freezes up in winter.

4. Forces necessary to maintain the track in perfect conditions.

The track for high-speed operation must always be maintained in perfect condition, as even the slightest defect, which is of no importance under low-speed operation, causes very rough riding at higher speeds. The vehicles strike the track with a force that may be considered to increase in proportion to the square of the train speed.

Statistics hitherto drawn up by the Japanese Government Rys. have shown that with an increase of 1 % in the mean speed of passenger trains, the labour required to maintain the track is also increased by 1 %. It is by no means the more economical method to have the track maintained by strengthening the gangs. The strengthening of the track must be considered first if the increased impact due to high-speed operation is to be overcome.

To reduce track maintenance work, it is best to adopt a heavier rail. Heavy rails unburden the sleepers, ballast and roadbed considerably, and small forces may be able to maintain the track in better condition. The advantage of heavier rails is the greater as the traffic increases.

Other methods of strengthening the track such as increasing the number of sleepers, improving the ballast of roadbed, etc. resorted to conjointly will also save maintenance work.

* * *

PART III.

Points and crossings to carry heavy loads at high speeds.

(Answers of railways with regard to this part are summarized in Table 25.)

1. Operating speed over points and crossings.

(1) Maximum permissible speed of the trains running on points and crossings.

When the tongue is machined from an ordinary flat-bottomed rail, it is laid on the foot of the stock rail and its surface is made 6 mm. to 10 mm. (15/64″ to 3/8″) higher than the head of the stock rail; this difference in level is usually run off in a short distance, i.e. with a relatively steep slope.

Thus the springs of coaches are suddenly contracted when they pass over the tongue rail, causing rolling to coaches.

When a wheel with conical tread passes over a crossing, it comes into contact with the wing rail at its outer part where the wheel diameter is relatively small, just before it runs onto the nose of the crossing, and then suddenly comes into contact with the nose rail at the inner part of the tyre with the larger diameter, and subsequently a heavy shock is imparted to the vehicle.

Such an upward movement is also found at the toe of a point where the gauge of the track is somewhat widened.

The construction of the tongue rail is generally very weak, and it is laid on the stock rail without any fastenings except the studs to prevent it from bending; therefore it can move vertically and laterally or tilt when the rolling stock passes over it, and smooth running is not to be expected.

Moreover, it is difficult to tamp the sleepers under points and crossings

TABLE 25. — P

RAILWAYS.	Maximum authorized speed on points and crossings.		
	1	2	3
	Maximum authorized speed over switches.	Maximum authorized speed over lead curves of various radii.	Difference betw maximum autho speed over fac and trailing po
Japan and China.			
Japanese Government . . .	...	$V = 2.75 \sqrt{R}$ km./h. R = radius in metres.	...
Chosen, Government-General.	...	...	...
Chinese Rys.	15 km. (*9.3 miles*) per hour 40 km. (*25 miles*) per hour	for unprotected point. for protected point.	...
Great Britain, Dominions and Colonies.			
London, Midland and Scottish	...	Differs according to the amount of superelevation.	...
London and North Eastern .	...	$V = 1.97 \sqrt{R}$ km./h. R = radius in metres. ($V = 5.5 \sqrt{R}$ miles per hour). R = radius in chains or $V = 3.367 \sqrt{N}$ km./h. ($V = 2.072 \sqrt{N}$ miles per hour). N = frog No.	For facing points 80.5 km./h. (*50 m* No restrictions f ling points.
Great Western	...	Speed in terms of km./h. is 0.08 — 0.1 times radius in terms of metres. (Speed in terms of miles per hour is 1 — 1 1/4 times radius in terms of chains).	...
Southern	...	20 km./h. (*12.5 miles*).	...
Great Northern	...	For facing points : 24.1 km./h. (*15 m.p.h.*).	...
Great Southern	...	...	...
Canadian National	On crossings : Passenger trains : 56.3 km./h. (*35 m.p.h.*). Other trains : 32.2 km./h. (*20 m.p.h.*).	..	...
Canadian Pacific	On diamond crossings : Passenger trains : 56.3 km./h. (*35 m.p.h.*). Goods trains : 32.2 km./h. (*20 m.p.h.*).	17.7 km./h. (*11 m.p.h.*) for No. 11 crossover with lead curve of 261 m. in radius. (6° — 12' — 47").	...
North Western (India) . . .	...	16.1 km./h. (*10 m.p.h.*).	...
Great Indian Peninsula . .	Speed is restricted on the un-interlocked switches.	16.1 km./h. (*10 m.p.h.*).	...
East Indian	No restriction on the interlocked switches.	16.1 km./h. (*10 m.p.h.*).	...
Madras and Southern Mahratta.	No restriction on the interlocked switches. In other cases 104.6 km./h. (*65 m.p.h.*).	16.1 km./h. (*10 m.p.h.*).	...
Bengal Nagpur	16.1 km./h. (*10 m.p.h.*).	16.1 km./h. (*10 m.p.h.*).	...

d crossings (1).

	Design of points and crossings.		
4	1	2	3
Minimum radius lead curves of switches r high-speed operation.	Length and angle of incidence of tongue for switches of maximum and minimum crossing (frog) numbers.	Type of curved tongues.	Difference in level between tongue and stock rails. Slope of top surface of tongue.
500 — 530 m. (*25 ch. — 26 1/2 ch.*).	...	Curved throughout the whole length, but the end of the blade has some incident angle.	For 50-kgr./m. rail : 10 mm. 1/100. For 37 and 30-kgr./m. rail : 7 mm. 1/150.
550 m. (*22 1/2 ch.*).	Max. and min. : 6.20 m. (*20' 4''*) 1o-12'.	...	8 mm. 1/40.
No. 10.	Max. : 5.50 m. (*18' 9/16''*). Spring rail : 12 m. (*39' 4 1/3''*).	...	...
...	No. 20 — 10.211 m. (*33' 6''*) — 1 : 80. No. 4 — 6.096 m. (*20' 0''*) — 1 : 24.	...	...
No. 16 : radius 746 m. (*2 446'*).	No. 16 — 8.687 m. (*28' 6''*) — 1 : 64. No. 7 — 6.096 m. (*20' 0''*) — 1 : 24.	Uses curved tongue rails but blade ends are straight.	...
...	No. 20 — 9.754 m. (*32'*) — 1 : 80 No. 3 1/2 — 3.353 m. (*11'*) — —	Curved throughout length.	...
40 ch.	No. 20 — 40' 6' — 1 : 90. No. 5 — 20' 0' — 1 : 24.	...	...
...	Nos. 9-14 — 8.687 m. (*28' 6''*) — 1 : 48. Nos. 5-12 — ... (...) — 1 : 40. Nos. 5-8 — 6.858 m. (*22' 6''*) — 1 : 32.	...	...
457 m. (*1 500'*).	7.315 m. (*24'*) — 1 : 64. 3.658 m. (*12'*) — 1 : 32.	...	...
o. 16 601 m. (*1 973'*). o. 20 1 011 m. (*3 309'*).	No. 20 — 10.058 m. (*33'*) — 51' 0''. No. 12 — 6.706 m. (*22'*) — 1o 16' 31''.	...	6 mm. (*1/4''*). Slope : 10.058 m. (*33'*) — 1 : 288. 6.706 m. (*22'*) — 1 : 192.
...	No. 13 — 6.706 m. (*22'*) — 1o 18' 8''. No. 6 — 3.353 m. (*11'*) — 1o 44' 11''.	..	6 mm. (*1/4''*) for 6.706 m. rail. 19.1 mm./2.743 m. (*3/4''/9'*) for 3.353 m. rail. 19.1 mm./1.524 m. (*3/4''/5'*).
222 m. (*729'*).	No. 12 — 6.655 m. (*21' 10''*) — 1o 8'. No. 8 1/2 — 4.724 m. (*15' 6''*) — 1o 34'.	.	13 mm. (*1/2''*). No slope.
244 m. (*800'*).	No. 12 — 5.486 m. (*18' 0''*) — 1o 11' 37''. 6.401 m. (*21' 0''*) — 1o 8' 0''. No. 8 1/2 — 3.658 m. (*12' 0''*) — 1o 47' 26''. 4.725 m. (*15' 6''*) — 1o 34' 27''.		6 mm. (*1/4''*). Slope : 1 : 172.
442 m. (*1 450'*).	6.404 m. (*21'*) — 1o 8' 0''. 4.724 m. (*15' 6''*) — 1o 34' 27''.		6 mm. (*1/4''*). 21' — 1 : 270. 15' 6'' — 1 : 194.
...	...	..	19 mm. (*3/4''*).
222 m. (*727'*).	No. 12 — 6.401 m. (*21'*) — 4o 45' 49''. No. 8 1/2 — 4.724 (*15' 6''*) — 6o 42' 35''.	...	6 mm. (*1/4''*).

TABLE 25. — P

RAILWAYS.	Maximum authorized speed on points and cr		
	1 Maximum authorized speed over switches.	2 Maximum authorized speed over lead curves of various radii.	3 Difference betw maximum autho speed over fac and trailing poi
Burma Rys.	For 75-lb. rail : 64.4 km./h. (*40 m.p.h.*). For 60-lb. rail : 56.3 km./h. (*35 m.p.h.*).	16.1 km./h. (*10 m.p.h.*). for the lead curve of 291 m. (*955'*) in radius.	...
Ceylon Government	...	...	...
New Zealand Government	...	Radius. Speed. 302 m. (*15 ch.*) — 14.5 km./h. (*9 m.p.h.*). 403 m. (*20 ch.*) — 19.3 km./h. (*12 m.p.h.*).	...
New South Wales Government.	...	201 m. (*10 ch.*) and less } 16.1 km./h. (*10 m.p.h.*). 221 m. (*11 ch.*) and over. } 40.3 km./h. (*25 m.p.h.*).	...
Sudan Government	25 km./h.	...	...
Nigerian Ry.	24.1 km./h. (*15 m.p.h.*).	16.1 km./h. (*10 m.p.h.*).	..
U. S. A.			
New York, Chicago and St. Louis.	...	Crossing No. Speed. No. 11. 24.1 km./h. (*15 m.p.h.*). No. 18. 56.3 km./h. (*35 m.p.h.*).	...
Southern Ry. Syst.	...	...	...
Reading Co.	...	V = 2 N m.p.h. V = speed. N = crossing No.	...
Northern Pacific	...	Crossing No. Radius of lead curve. Speed. No. 11 292 m. (*5°-59'-22''*) 40.2 km./h. (*25 m.p.h.*). No 16 643 m. (*2°-43'-12''*) 56.3 km./h. (*35 m.p.h.*).	...
Atchison, Topeka and Santa Fe.	...	Radius. Speed. 1 010 m. (*3 317'*). 56.3 km./h. (*35 m.p.h.*). 476 m. (*1 562'*). 40.2 km./h. (*25 m.p.h.*).	...
Baltimore and Ohio	...	Crossing. Radius. Speed. No. 10 245 m. (*803'*) 24.1 km./h. (*15 m.p.h.*). No. 16 653 m. (*2 141'*) 48.2 km./h. (*30 m.p.h.*). No. 20 1 028 m. (*3 372'*) 56.3 km./h. (*35 m.p.h.*).	For trailing poin restriction. For un facing points : 48,2 (*30 m.p.h.*).
New York, New Haven and Hartford.	...	Specificaion of A. R. E. A.	...
Chicago, Burlington and Quincy.	...	Crossing No. Speed. No. 20 80.5 km./h. (*50 m.p.h.*). No. 15 64.4 km./h. (*40 m.p.h.*). No. 11 24.1 km./h. (*15 m.p.h.*).	Speed is restricte on the spring poi
Norfolk and Western	...	Crossing Radius. Speed. No. 8 139 m. (*12°-31'*) 19.3 km./h. (*12 m.p.h.*). No. 10 250 m. (*7°-0'*) 24.1 km./h. (*15 m.p.h.*). No. 12 336 m. (*5°-12'*) 40.2 km./h. (*25 m.p.h.*). No. 15 576 m. (*3°- 2'*) 56.3 km./h. (*35 m.p.h.*). No. 20 1 047 m. (*1°-40'*) 72.4 km./h. (*45 m.p.h.*).	...
Delaware and Hudson	...	V = 2 N m.p.h.	...

l crossings (I). (*Contd.*)

	Design of points and crossings.		
4	1	2	3
Minimum radius lead curves of switches high-speed operation.	Length and angle of incidence of tongue for switches of maximum and minimum crossing (frog) numbers.	Type of curved tongues.	Difference in level between tongue and stock rails. Slope of top surface of tongue.
...	3.658 m. (*12'*) — 1° 43' 43''.	...	6 mm. (*1/4''*).
...	...	...	...
nerally : 241 m. (*12 ch.*). cial case : 181 m. (*9 ch.*).	No. 12 — 6.096 m. (*20'*) — 1° 0' 53''. No. 9 — 4.572 m. (*15'*) — 1° 21' 11''.	...	6 mm. (*1/4''*).
181 m. (*9 ch.*).	6.096 m. (*20'*) — 1° 29' 32''.	Curved tongues 30' long : 0° 20' 37''. Tongues with straight section 10' long and curved section 20' long : 0° 44' 46''.	0 and 6 mm. (*1/4''*). Slope : 1 : 256.
617 m. (*2 022'*).	3.658 m. (*12'*) — 1° 20'. 4.752 m. (*15'*) — 1° 40'.	...	25 mm. (*1''*).
137 m. (*450'*).	3.658 m. (*12'*) — 1° 0'.	...	32 mm. (*1 1/4''*).
No. 18 : 788 m. (*2 584'*).	No. 18 — 9.144 m. — (*30'*). No. 12 — 6.706 m. — (*22'*). No. 11-No. 7 — 5.029 m. — (*16' 6''*). No. 5 — 3.353 m. — (*11'*).	...	13 mm. (*1/2''*).
...	...	...	...
Min. : 541 m. (*1 775'*). dinary : 1 016 m. (*3 337'*).	9.144 m. (*30'*) — 0° 54' 55''. 6.096 m. (*20'*) — 1° 27' 45''. 4.572 m. (*15'*) — 1° 49' 50''. 3.048 m. (*10'*) — 2° 44' 48''.	Used for double slip switches.	...
). 16 : 643 m. (2°-43'-12'').	No. 16 — 6.706 m. (*22'*) — 1° 14' 53''. No. 11 — 5.029 m. (*16' 6''*) — 1° 39' 51''.	...	6 mm. (*1/4''*). Slope : 19,1 mm./2.134 m. (*3/4''/7'*).
476 m. (*1 562'*).	No. 20 — 9.144 m. (*30'*) — 54' 55''. No. 14 — 6.700 m. (*22'*) — 1° 18' 8''.	...	6 mm. (*1/4''*).
245 m. (*803'*).	No. 20 — 9.144 m. (*30'*) — 59' 23''. No. 16 — 7.315 m. (*24'*) — 1° 14' 15''. No. 10 — 5.029 m. (*16' 6''*) — 1° 47' 56''.	...	6 mm. (*1/4''*). No. 20 : 19.1 mm./2.743 m. (*3/4''/9'*). No. 16 : 19.1 mm./2.286 m. (*3/4''/7' 6''*). No. 10 : 19.1 mm./1.524 m. (*3/4''/5'*). A. R. E. A. specification.
609 m. (*2 190'*).	9.144 m. (*30'*) — 0° 57'. 7.315 m. (*24'*) — 1° 12'. 4.572 m. (*15'*) — 1° 55'.	...	
1 046 m. (*3 434'*).	No. 20 — 9.144 m. (*30'*) — 52' 31''. No. 7 — 5.029 m. (*16' 6''*) — 1° 39' 51''.	...	...
. 15 : radius 576 m. (*1 900'*).	9.144 m. (*30'*) — 0° 57'. 5.029 m. (*16' 6'*) — 1° 44'.	...	6 mm. (*1/4''*). A. R. E. A. specification.
). 10 : 235 m. (7°-27'-7'').	No. 20 — 0° 57' 18''. No. 10 — 1° 44' 11''.	Uses tongue curved uniformly on the special place.	13 mm. (*1/2''*). 9.144 m. 6.4 mm./3.655 m. (*30' 1/4''/12'*). 5.029 m. 6.4 mm./2.134 m. (*16' 6'' 1/4''/7'*).

TABLE 25. — Po

RAILWAYS.	Maximum authorized speed on points and crossi		
	1	2	3
	Maximum authorized speed over switches.	Maximum authorized speed over lead curves of various radii.	Difference betwe maximum authori speed over faci and trailing poi
Chesapeake and Ohio	...	Specification of A. R. E. A.	...
Illinois Central	For spring points : 40.2 km./h. (*25 m.p.h.*).	Crossing No. — Speed. No. 10 — 24.1 km./h. (*15 m.p.h.*). No. 12-14 — 32.2 km./h. (*20 m.p.h.*). No. 15 — 40.2 km./h. (*25 m.p.h.*). No. 18 — 48.2 km./h. (*30 m.p.h.*).	...
Great Northern	For interlocked switches : 48.2 km./h. (*30 m.p.h.*).	Crossing No. — Speed. No. 20-24 — 64.4 km./h. (*40 m.p.h.*). No. 15 — 59.6 km./h. (*37 m.p.h.*). No. 14-11 — 35.4 km./h. (*22 m.p.h.*). No. 10-8 — 25.7 km./h. (*16 m.p.h.*). No. 7-5 — 19.3 km./h. (*12 m.p.h.*).	...
Atlantic Coast Line	...	Crossing No. — Speed. No. 5-6 — 16.1 km./h. (*10 m.p.h.*). No. 7-8 — 24.1 km./h. (*15 m.p.h.*). No. 10 — 32.2 km./h. (*20 m.p.h.*). No. 11-12-14 — 40.2 km./h. (*25 m.p.h.*). No. 16-18-20 — 48.2 km./h. (*30 m.p.h.*).	...
Florida East Coast	...	Crossing No. — Radius — Speed. No. 20 — 1 013 m. (*3 322'*) — 64.4 km./h. (*40 m.p.h.*) No. 11 — 238 m. (*780'*) — 32.2 km./h. (*20 m.p.h.*). No. 8 — 149 m. (*487'*) — 19.3 km./h. (*12 m.p.h.*).	...
Chicago, Rock Island and Pacific.	...	Crossing No. — Speed. No. 20 — 56.3 km./h. (*35 m.p.h.*). No. 10 — 16.1 km./h. (*10 m.p.h.*).	...
Pere Marquette	...	Crossing No. — Speed. No. 10 — 16.1 km./h. (*10 m.p.h.*). No. 15 — 32.2 km./h. (*20 m.p.h.*). No. 20 — 48.2 km./h. (*30 m.p.h.*).	...
New York Central	For interlocked switches : 96.6 km./h. (*60 m.p.h.*).	Crossing No. — Speed. Nos. 10-12 — 24.1 km./h. (*15 m.p.h.*). No. 14 — 32.2 km./h. (*20 m.p.h.*). Nos. 16-18 — 48.2 km./h. (*30 m.p.h.*). In yards — 16.1 km./h. (*10 m.p.h.*).	...
Pennsylvania	...	Radius. — Speed. 1 858' and over — 48.2 km./h. (*30 m.p.h.*). 1 845'—457' — 24.1 km./h. (*15 m.p.h.*). 457' and less — 16.1 km./h. (*10 m.p.h.*).	...
Missouri Pacific	...	Crossing — Radius — Speed. No. 10 — 202 m. (*663'*) — 16 km./h. (*10 m.p.h.*). No. 20 — 560 m. (*3 145'*) — 48.2 km./h. (*30 m.p.h.*).	...
Southern Pacific	...	...	...
Delaware, Lackawanna and Western.	...	Crossing No. — Speed. No. 10 — 24.1 km./h. (*15 m.p.h.*). No. 14 — 32.2 km./h. (*20 m.p.h.*). No. 20 — 48.2 km./h. (*30 m.p.h.*).	...
Other Countries.			
Entre Rios	For switches interlocked with signals : 30 km./h. For switches interlocked with manual signals : 20 km./h.	10 km./h.	...
Central Cordoba	For facing points : 25 km./h. For trailing points : No restriction.	12 km./h.	...
Paulista	For facing points : 70 km./h. For trailing points : 90 km./h.	30 km./h.	50 km./h. 30 km./h.
Buenos Ayres and Pacific	No restriction on interlocked switches.	...	...

d crossings (I). (*Contd.*)

	Design of points and crossings.		
4	1	2	3
Minimum radius lead curves of switches r high-speed operation.	Length and angle of incidence of tongue for switches of maximum and minimum crossing (frog) numbers.	Type of curved tongues.	Difference in level between tongue and stock rails. Slope of top surface of tongue.
123 m. (*405'*).	9.144 m. (*30'*) — 57' 18''.	...	6 mm. (*1/4''*).
No. 18 : 873 m. (*2' 09''*).	5.029 m. (*16' 6''*) — 1° 44' 11''.		6.4 mm./2.134 m. (*1/4''/7'*).
	7.315 m. (*24'*) — 1° 9'.	...	13 mm. (*1/2''*).
	5.029 m. (*16' 6''*) — 1° 44'.		12.7 mm./5.486 m. (*1/2''/18'*).
1 013 m. (*3 322'*).	9.144 m. (*30'*) — 57' 18''.	...	13 mm. (*1/2''*).
No. 16.	No. 20 — 8.230 m. — (*27'*).	...	6 mm. (*1/4''*).
	No. 8 or less — 3.658 m. — (*12'*).		
...	No. 20 — 9.144 m. (*30'*) — 57' 18''.	...	6 mm. (*1/4''*).
	No. 8 — 5.029 m. (*16' 6''*) — 1° 44' 11''.		9.144 m. 19.1 mm./3.658 m. (*3/4''/12'*).
			5.029 m. 19.1 mm./2.134 m. (*3/4''/7'*).
543 m. (*1 781'*).	No. 20 — 9.144 m. (*30'*) — 57' 18''.	...	3 mm. (*1/8''*).
	No. 10 — 5.029 m. (*16' 6''*) — 1° 39' 50''.		Slope : 3.2 mm./1.810 m. (*1/8''/5' 11 1/2''*).
o. 20 : 1 013 m. (*3 322'*).	No. 20 — 9.144 m. (*30'*) — 57' 18''.	...	13 mm. (*1/2''*).
	No. 10 — 5.029 m. (*16' 6''*) — 1° 44' 11''.		
...	No. 18 — 9.144 m. (*30'*) — 57' 18''.	...	...
	No. 10 — 5.029 m. (*16' 6''*) — 1° 44' 11''.		
234 m. (*768'*).	13.716 m. (*45'*) — 0° 22'.	...	8 mm. (*5/16''*).
	3.048 m. (*10'*) — 2° 41' 12''.		
...	No. 20 — 9.144 m. (*30'*) — 57' 18''.	...	6 mm. (*1/4''*).
	No. 8 1/2 — 4.572 m. (*15'*) — 1° 40' 17''.		No. 20 19.1 mm./3.658 m. (*3/4''/12'*).
			No. 8 1/2 19.1 mm./1.829 m. (*3/4''/6'*).
...	...	...	...
826 m. (*2 707'*).	9.144 m. (*30'*) — 56' 6''.	...	...
	5.029 m. (*16' 1''*) — 1° 42' 0'').		
...	4.78 m. — 1° 30'.	...	The same.
	3.66 m. — 1° 58'.		
145 m.	No. 12 — 5.486 m. (*18'*) — 1° 8' 40''.	...	32 mm. (*1 1/4''*).
	No. 10 — 4.572 m. (*15'*) — 1° 22' 24''.		
	No. 10 — 3.658 m. (*12'*) — 1° 42' 59''.		
No. 14 : 537 m.	No. 14 — 6.706 m. (*22'*) — 1° 18' 8''.	...	6 mm. (*1/4''*).
	No. 12 — 6.706 m. (*22'*) — 1° 18' 8''.		Slope : 1/180.
	No. 10 — 5.029 m. (*16' 6''*) — 1° 44' 11''.		(*1/4''/3' 9''*).
333 m.	No. 16 — 7.315 m. (*24'*) — 0° 52' 48''.	...	6 mm. (*1/4''*).
	No. 8 — 4.572 m. (*15'*) — 1° 24' 29''.		Slope : 1/180.

TABLE 25. — Pe

RAILWAYS.	Design o			
	4	5	6	7
	Kind of special tongues used, and results obtained.	Section of tongue rail.	Tongue rails made of special steel and results obtained.	Maximum and minimur crossing (frog) nu
Japan and China.				
Japanese Government . . .	...	...	...	Min.: No. 8 Max.: No. 16
Chosen, Government-General.	...	Machined from ordinary rails.	...	Min.: No. 12 Max.: No. 15
Chinese Rys.	Long point rails.	Do.	...	Min.: No. 10 Max.: No. 12
Great Britain, Dominions and Colonies.				
London, Midland and Scottish	Long point rails.	Machined from ordinary rails.	Chrome-steel and manganese-steel rails.	Max.: No. 20
London and North-Eastern .	Long point rails. 8.687 m. (28' 6").	Do.	Manganese-steel tongues in terminals. Satisfactory.	Max.: No. 16
Great Western	Housed switch rails.	Do.	...	Max.: No. 20
Southern	Long point rails. Satisfactory.	Machined from ordinary rails.	...	Min.: No. 8 Max.: No. 20
Great Northern	...	Do.	...	Min.: No. 8 Max.: No. 14
Great Southern	Long point rails.	Do.	...	Min.: No. 8 Max.: No. 16
Canadian National	Do.	Do.	Tongues with manganese tip. Satisfactory.	Min.: No. 12 Max.: No. 20
Canadian Pacific	Do.	Do.	...	Min.: No. 6 Max.: No. 13
North-Western (India) . . .	...	Do.	Chrome-steel.	Min.: No. 8 Max.: No. 12
Great Indian Peninsula . .	Long point rails.	Do.	Manganese-steel for heavier rails.	Do.
East Indian	...	Do.	...	Do.
Madras and Southern Mahratta	6.401 m. (21').	Do.	Chrome-steel rails.	Do.
Bengal Nagpur	Both long point rails and stub point rails.	Do.	...	Do.
Burma Rys.	...	Machined from ordinary rails.	...	...
Ceylon Government	...	...	...	...
New Zealand Government .	...	Machined from ordinary rails.	...	Min.: No. Max.: No. 1
New South Wales Government	Long point rails.	Do.	...	Min.: No. 7 Max.: No. 1
Sudan Government	Stub points. Satisfactory.	Do.	...	Min.: No. Max.: No. 1
Nigerian Ry.	Long point rails.	Do.	...	Min.: No. Max.: No. 1
U. S. A.				
New York, Chicago and St. Louis	...	Machined from ordinary rails.	Manganese-steel and heat-treated carbon steel. Satisfactory.	Min.: No. Max.: No. 1

d crossings (II).

ssings.

8	9	10	11
Construction of crossings.	Kinds of movable crossings used and results obtained.	Use of special steel crossings.	Radius and gauge widening of curved crossings, and results obtained.
Built up.	Movable nose, rail type.	...	Bent to suit switch curve.
Built up.	...	Tentatively.	...
oth built-up and one-piece.	...	Manganese-steel crossing. Satisfactory.	...
Built up.	Adopts.	...	...
Do.	Ensures comfortable riding and prevents danger, but uneconomical.	Life of crossing lengthened by adoption of manganese or chrome-steel.	...
Do.	Adopts tentatively.	Manganese-steel crossing.	No widening.
Built up.	...	...	No widening.
Do.	...	Manganese-steel crossings. Satisfactory.	...
Do.	...	...	. .
Do.	A. R. E. A. type slip switches.	Manganese-steel crossings. Durable.	...
Do.	No. 9 and No. 11 spring wing-rail type. Satisfactory.	Manganese-steel crossings. Satisfactory.	...
Do.	...	Tentatively chrome-steel crossings Satisfactory.	...
Do.	...	Manganese-steel.	...
Do.	...	Manganese-steel crossings; good but uneconomical.	...
Do.	...	...	...
Do.	...	...	...
Built up.	...	...	...
...	. .	...	...
Built up.	...	...	...
Built up and one-piece.	...	Both built up and one-piece mangnaese-steel crossings are showing satisfactory results. Latter is expensive.	Widen gauge in switch curves sharper than R = 603 m. (*30 ch.*). Satisfactory.
Built up.	...	...	...
Do.	...	...	...
Built up.	A. R. E. A. type manganese knuckle rail.	Manganese-steel and heat-treated steel show the best results.	...

TABLE 25. — Points

RAILWAYS.	Design o			
	4	5	6	7
	Kind of special tongues used, and results obtained.	Section of tongue rail.	Tongue rails made of special steel and results obtained.	Maximum and minimu crossing (frog) n
Southern Ry. Syst.	...		...	...
Reading Co.	...	Machined from ordinary rails.	Manganese-steel.	Min. : No. Max. : No. 2
Northern Pacific	...	Machined from ordinary rails.	...	Min. : No. 1 Max. : No. 1
Atchison, Topeka and Santa-Fe.	...	Do.	...	Min. : No. 1 Max. : No. 2
Baltimore and Ohio	Long point rails. Satisfactory.	Do.	Manganese-steel. Long life.	Min. : No. 1 Max. : No. 2
New York, New Haven and Hartford.	Long point rails.	Do.	...	Min. : No. Max. : No. 2
Chicago, Burlington and Quincy.	Do.	Do.	...	Min. : No. Max. : No. 2
Norfolk and Western . . .	Do.	Do.	...	Min. : No. Max. : No. 2
Delaware and Hudson . . .	Do.	« Sampon » switches; undercut stock rails.	Manganese steel.	Min. : No. 1 Max. : No. 2
Chesapeake and Ohio . . .	...	Machined from ordinary rails.	...	Min. : No. Max. : No. 1
Illinois Central	Long point rails.	Do.	...	Min. : No. Max. : No.
Great Northern	Do.	Do.	...	...
Atlantic Coast Line	Long point rails.	Machined from ordinary rails.	Manganese-steel in places where wear is heavy. Satisfactory.	Main line : No Track for high-speed operation. } No No
Florida East Coast	Do.	Do.	...	Min. : No. Max. : No.
Chicago, Rock-Island and Pacific.	...	Do.	...	Min. : No. Max. : No.
Pere Marquette	...	Do.	...	Do.
New York Central	Long point rails.	Do.	Heat-treated carbon steel and manganese-steel. Satisfactory.	Min. : No. Max. : No.
Pennsylvania	Long point rails. Satisfactory.	Do.	...	Min. : No. Max. : No.
Missouri Pacific	...	Do.	...	Min. : No. Max. : No.
Southern Pacific	...	...	...	...
Delaware, Lackawanna and Western.	...	Machined from ordinary rails.	...	Min. : No. Max. : No.
Other Countries.				
Entre Rios	...	Do.	...	Min. : No. Max. : No.
Central Cordoba	Long point rails.	Do.	...	Min. : No. Max. : No.
Paulista	Do.	Do.	...	Min. : No. Max. : No.
Buenos-Ayres and Pacific . .	Do.	Do.	...	Min. : No. Max. : No.

ossings (II). (*Contd.*)

ossings.

8	9	10	11
Construction of crossings.	Kinds of movable crossings used and results obtained.	Use of special steel crossings.	Radius and gauge widening of curved crossings, and results obtained.
...	...	...	...
Built up and one-piece.	Movable rails shaped from ordinary rails and knuckles are solid manganese-steel.	Manganese-steel. Durable.	...
il bound manganese crossing.	Spring rails.	...	...
Built up and one-piece.	Do.	Manganese-steel. Long life.	Bent to suit switch curve.
One-piece.	Nos. 8 and 10 movable crossings.	Manganese-steel solid crossings. Economical.	...
Built up.	A. R. E. A. specification.	...	...
Built up and one-piece.	...	...	Bent to suit switch curve.
...	A. R. E. A. specification.	Manganese-steel crossings. Long life.	...
Built up and one-piece.	Manganese-steel movable crossings.	Manganese-steel.	...
Rail bound manganese-steel type.	...	...	Widening same as ordinary curves. Satisfactory.
Built up and one-piece.	...	Heat-treated manganese-steel. Long life.	...
Do.	...	...	Gauge generally widened as radius decreases. Satisfactory.
Built up and one-piece.	...	Manganese-steel. Satisfactory.	...
Do.	...	...	Bent to suit switch curves. Gauge widened the same as in ordinary curves.
Articulated manganese.	...	Manganese-steel. Satisfactory.	Same as ordinary curves.
Built up and one-piece.	...	...	Bent to suit lead curve.
Do.	For crossings whose intersecting angle $< 9^{o}$.	Manganese-steel.	Curvature and gauge the same as lead curve.
ilt up, rail bound manganese.	Made of ordinary rails. Satisfactory.	Manganese-steel crossing where necessary. Satisfactory.	Varying radii, generally no widening of gauge.
Built up and one-piece. Manganese.	Nos. 8 1/2, 10 spring crossings. Comfortable riding secured, but maintenance of gauge is difficult.	Manganese-steel.	Gauge widened same amount as ordinary curves. Satisfactory.
...	...	...	...
Built up.	...	Rail bound manganese crossings. Satisfactory.	...
Do.	...	...	...
One-piece and built up.	...	Life of manganese-steel about twice that of ordinary steel.	...
Built up.	...	...	...
Do.	...	...	...

TABLE 25. - F

RAILWAYS.	Design of	
	12	13
	Guard rails.	
	Length.	Angle of spread at ends.	Difference in level between guard rail and stock rail.	Width of flangeway.	Kin of faste used for and cro
Japan and China.					
Japanese Government	...	...	...	...	...
Chosen, Government-General.	3.05 m.	About 10°.	Same level.	42 mm.	Coach-s
Chinese Rys.	...	...	...	...	Dog s and coac
Great Britain, Dominions and Colonies.	...	...	...	...	...
London, Midland and Scottish.	3.200 — 5.486 m. (*10' 6'' — 18' 0''*).	1 : 18	Same level.	44.5 mm. (*1 3/4''*).	Chair-s
London and North-Eastern	3.200 — 5.563 m. (*10' 6'' — 18' 3''*).	Do.	Do.	Do.	Do
Great Western	Intersecting angle. 1 : 2 — 1 : 7 1/2 : 3.505 m. (*11' 6''*). 1 : 7 3/4 — 1 : 11 : 4.267 m. (*14''*) 1 : 11 1/2 — 1 : 16 : 4.877 m. (*16''*) 1 : 20 : 6.248 m. (*20' 6''*)	1 : 24	Same level.	44.5 mm. (*1 3/4''*).	Fang
Southern	3.962 — 4.724 m. (*13' — 15' 6''*).	1 : 17	Do.	Do.	Coach-s
Great Northern	...	...	...	...	Chair-s
Great Southern	3.200 — 4.013 m. (*10' 6'' — 13' 2''*).	44.5/457 mm. (*1 3/4''-1' 6''*).	...	44.5 mm. (*1 3/4''*).	Bol
Canadian National	...	...	Same level.	47.6 mm. (*1 7/8''*).	Dog s
Canadian Pacific	No. 6 — No. 12 : 2.019 m. (*6' 7 1/2''*). No. 13 : 2.918 m. (*8' 11''*).	Entrance : 8° 53'. Inner part : 3° 18'	Do.	Straight part 47.6 mm. (*1 7/8''*).	Do
North Western (India)	3.962 m. (*13'*).	Length : 254 mm. (*10''*) from end bent with R = 914 mm. (*3'*).	...	...	Do
Great Indian Peninsula	3.048 m. (*10'*). 3.962 m. (*13'*).	Do.	44.5 — 47.6 mm. (*1 3/4'' — 1 7/8''*).	...	Fang

] crossings (III).

rossings.						
14	15	16	17	18	19	20
Rail braces on lead curves.	Gauge widening of lead curves.	Superelevation of outer rail of simple switches.	Superelevation of outer rails of double switches.	Length of straight section inserted between switches and adjoining curves.	Are ordinary switches used for emergency crossovers?	Are ordinary switches used for catch sidings?
. but of late ng replaced by ring plates.	Max. : 19 mm.	Generally none.	Given.	10 m.	Continuous-rail points adopted.	Continuous-derailing points adopted.
...	13 mm. on curves sharper than 550 m. radius.	...	...	...	...	Yes.
...	Same as for ordinary curves.	...	...	...	Yes.	Yes.
...	...	...	...	...	...	Yes.
retcher bars.	...	...	...	...	Yes.	Yes.
...	Same as for ordinary curves.	...	...	...	Yes.	Yes, where necessary.
...	161 — 211 m. 6.4 mm. (*8-10 ch.*) (*1/4''*).	...	...	...	Yes.	...
...	...	...	...	...	Yes.	Yes.
...	...	...	...	18.288 m. (*60'*).	Yes.	Yes.
...	...	...	...	...	Yes.	Yes.
...	Same as for ordinary curves.	...	...	...	Yes.	...
...	Do.	...	...	...	Yes.	...
...	...	...	...	...	Yes.	Yes.
...	...	...	...	...	No.	Yes.

TABLE 25. - Points

RAILWAYS.	Design of r				
	12				13
	Guard rails.				
	Length.	Angle of spread at ends.	Difference in level between guard rail and stock rail.	Width of flangeway.	Kin of faste used for and cro
East Indian	3.962 m. (13').	Length of 30.5 mm. (1') from end is bent with R = 914 mm. (3').	Same level.	44.5 mm—47.6 mm (1 3/4" — 1 7/8").	Dog s
Madras and Southern Mahratta.	...	...	...	...	...
Bengal Nagpur	3.962 m. (13').	Both ends are bent with R = 914 mm. (3').	Same level.	44.5 mm. (1 3/4").	Both dog and coac
Burma Rys.	3.810 m. (12' 6").	Do.	4 mm. (5/32").	41.3 mm. (1 5/8").	Dog s
Ceylon Government	...	...	...	...	...
New Zealand Government.	No. 12 3.658 m. (12'). No. 9 3.200 m. (10' 6").	1/8 (1 1/2"/12").	Same level.	38.1 mm. (1 1/2").	Coach-s
New-South-Wales Government.	4.064 m. (13' 4").	1 : 60	Do.	44.5 mm. (1 3/4").	22 mm. (7 coach-s
Sudan Government	2.743 m. (9'). 3.200 m. (10' 6"). 3.658 m. (12').	1 : 5	Do.	Do.	Coach-s
Nigerian Ry.	2.743 m. (9').	Both ends are bent with R = 6.553 m. (21' 6").	Do.	Do.	Dog s
U. S. A.					
New York, Chicago and St. Louis	3.353 m. (11').	44.5/533 mm. (1 3/4" — 21').	Same level.	47.6 mm. (1 7/8").	Coach- and dog
Southern Railway	...	...	...	...	...
Reading Co.	4.877 m. (16').	...	Same level.	44.5 mm. (1 3/8"). 50.8 mm. (2"). 57.2 mm. (2 1/4").	Dog
Northern Pacific	3.353 m. (11').	108/610 mm. (4 1/4" — 24').	Do.	44.5 mm. (1 3/4").	I
Atchison, Topeka and Santa Fe.	2.743 m. (9'). 3.658 m. (12'). 4.572 m. (15').	...	Do.	47.6 mm. (1 7/8").	I
Baltimore and Ohio	Sufficient length to protect crossing.	41.3/457 mm. (1 5/8" — 18').	Do.	47.6 — 60.3 mm. (1 7/8" — 2 3/8").	I
New York, New Haven and Hartford.	4.572 m. (15').	44.5-76.2/838 mm. (1 3/4"-3"-2' 9").	Do.	44.5 mm. (1 3/4").	1

ssings (III). (*Contd*).

rossings.

14	15	16	17	18	19	20
Rail braces on lead curves.	Gauge widening of lead curves.	Superelevation of outer rail of simple switches.	Superelevation of outer rails of double switches.	Length of straight section inserted between switches and adjoining curves.	Are ordinary switches used for emergency crossovers?	Are ordinary switches used for catch sidings?
...	...	...	...	...	Yes.	Yes.
...	...	...	...	...	...	Yes.
...	...	...	...	...	Yes.	Yes.
...	...	...	...	...	Yes.	Yes.
...	...	...	...	...	...	...
...	At heel : 0. At point 3.048 m. (*10'*) from heel : 13 mm. (*1/2''*).	...	...	...	Yes.	Yes
...	Same as for ordinary curves.	...	...	...	Yes	Yes.
...	...	...	...	...	...	Yes.
...	...	...	...	...	Yes.	Yes.
..	None in curves R $\geqslant$ 291 m. (*14.5 ch.*). Maximum : 25 mm. (*1''*).	No.	...	...	Yes.	Yes.
...	...	...	...	...	...	...
...	Nos. 15, 20 : 0 mm No. 12 : 6 mm. Nos. 6, 8 : 15 mm.	...	...	...	...	...
Yes	...	...	...	...	Yes.	...
Yes	...	...	...	...	Yes.	Yes.
...	...	...	...	...	Yes.	Yes.
...	...	...	...	...	Yes.	Yes.

TABLE 25. - Points

RAILWAYS.	Design of poi				
	12				13
	Guard rails.				
	Length.	Angle of spread at ends.	Difference in level between guard rail and stock rail.	Width of flangeway.	Kind of fasteni used for sw and crossi
Chicago, Burlington and Quincy.	...	A. R. E. A. specification.	...	...	Do.
Norfolk and Western . . .	...	Do.	...	...	Do.
Delaware and Hudson . . .	5.029 m. (*16' 6''*). 6.096 m. (*20'*).	5° 21'	Same level.	44.5 mm. (*1 3/4''*).	Coach-scre
Chesapeake and Ohio . . .	3.353 m. (*11'*). 5.029 m. (*16' 6''*).	...	...	...	Dog spik
Illinois Central	...	A. R. E. A. specification.	Same level.	47.6 mm. (*1 7/8''*).	Do.
Great Northern	...	...	Do.	...	Do.
Atlantic Coast Line	...	A. R. E. A. specification.	Do.	A. R. E. A. specification.	Do.
Florida East Coast	...	44.5/457 mm. (*1 3/4'' — 18'*).	Do.	44.5 mm. (*1 3/4''*).	Do.
Chicago, Rock-Island and Pacific.	Sufficient length to protect crossing.	54.0/457 mm. (*2 1/8'' — 18'*).	Do.	47.6 mm. (*1 7/8''*).	Do.
Pere Marquette	← A. R. E. A. specification. →			...	Do.
New York Central	...	Do.	...	...	Do.
Pennsylvania	2.769 m. (*9' 1''*).	41.3/800 mm. (*1 3/8''—2' 7 1/2''*).	Same level.	44.5 mm. (*1 3/4''*).	Do.
Missouri Pacific	...	15.9/508 mm. (*5/8'' — 20''*).	Do.	47.6 mm. (*1 7/8''*).	Do.
Southern Pacific	...	...	...	...	...
Delaware, Lackawanna and Western.	2.743 m. (*9'*).	...	...	47.6 mm. (*1 7/8''*).	Dog spik
Other Countries.					
Entre Rios	3.048 m. (*10'*).	...	Same level.	44.5 mm. (*1 3/4''*).	Coach-scr
Central Cordoba	3.048 m. (*10'*).	45°	Do.	50.8 mm. (*2''*).	Coach-scr
Paulista	...	A. R. E. A. specification.	...	...	Do.
Buenos-Ayres and Pacific . .	3.12 m.	...	Same level.	47.6 mm. (*1 7/8''*).	Do.

ossings (III). (*Contd*).

crossings.

14	15	16	17	18	19	20
Rail braces on lead curves.	Gauge widening of lead curves.	Superelevation of outer rail of simple switches.	Superelevation of outer rails of double switches.	Length of straight section inserted between switches and adjoining curves.	Are ordinary switches used for emergency crossovers?	Are ordinary switches used for catch sidings?
...	Same as for ordinary curves.	...	...	...	Yes.	...
Yes.	Where necessary.	...	Yes.	...	Yes.	Yes.
...	...	...	...	...	Yes.	Yes.
Yes.	...	...	...	...	Yes.	Yes.
Yes.	Same as for ordinary curves.	...	...	...	No.	No.
Yes.	...	...	...	...	Yes.	Yes.
Yes.	...	...	...	...	Yes.	Yes.
...	...	...	...	...	Yes.	Yes.
...	Same as for ordinary curves.	..	...	...	Yes.	Yes.
...	A. R. E. A. specification.	...	...	...	Yes.	Yes.
...	Same as for ordinary curves.	...	...	...	Yes.	Yes.
...	...	...	...	...	Yes.	No.
...	Same as for ordinary curves.	...	...	...	No.	Yes.
...	...	...	...	...	...	...
...	...	...	...	..	Yes.	Yes.
...	5 mm.	..	..	...	Yes.	No.
...	...	...	...	0.94 m. at switches. 2.90 m. at crossings. ends.	...	...
...	...	...	...	...	Yes.	Yes.
...	...	...	...	...	Yes.	Yes.

sufficiently, as the various accessories hinder such maintenance work.

When such points and crossings are laid in series the natural oscillation of the rolling stock will often resonate with the forced oscillation due to irregularities of the rail surface, and in the worst case cause derailment.

Wagons with a high centre of gravity are most dangerous. It is necessary to restrict the operating speed within a proper limit in the yards if undue oscillation of rolling stock is to be prevented. But most railways set no restriction upon the operating speed of passenger trains in yards, when running over points and crossings. The New York Central Lines fix the maximum permissible speed over the interlocked crossings at 60 miles (96.6 km.) per hour, and the Canadian National Rys. and the Canadian Pacific Ry. restrict the operating speed of passenger trains to 35 miles (56.3 km.) per hour, and that of other trains to 20 miles (32.2 km.) per hour over diamond crossings.

In principle, the Japanese Government Rys. lay down no speed restriction over points and crossings, but at special points where oscillation of rolling stock is especially severe, the operating speed is often restricted to under 80 km. (50 miles) per hour. However, they have recently adopted improved switch rails designed for high speed operation, and movable crossings in place of the old type of points and crossings, and are endeavouring to withdraw the speed restrictions mentioned above.

(2) Maximum speeds permissible over point curves.

Irregularities of the running surface at points and crossings already cause heavy shocks to the vehicles running on the straight on main lines, will apparently cause still heavier oscillations to the rolling stock when running over point curves. Furthermore, as the tongue rail makes an incident angle with the stock rail, the angular velocity of the vehicle is changed suddenly at the toe of the tongue rail from zero to a certain amount. The greater the operating speed, the heavier is the shock to the passengers.

Generally speaking, the switch curve is not provided with a theoretical amount of superelevation or gauge widening, so that smooth running of rolling stock through switch curves is more difficult to obtain than in the ordinary curve.

For the above reasons the operating speed in the lead curves should be restricted more severely than in ordinary curves of the same radii, to ensure the same degree of safety in both cases.

The Japanese Government Rys. specify the maximum permissible speeds over switch curves of various radii as follows :

$$V_{max.} = 2.75 \sqrt{R}$$

wherein

$V_{max.}$ = maximum permissible speed in km./hour,

R = radius of curve in metres,

as compared with the case of ordinary curves whose maximum speeds are computed by the following formula :

$$V_{max.} = 3.5 \sqrt{R}$$

A number of standard-gauge railways restrict the train speed on No. 10 switches to between 10 and 20 miles (16.1 and 32.2 km.) per hour, and as the mean 15 miles (24.1 km.) per hour; on No. 20 switches from 30 to 50 miles (48.2 and 80.5 km.) per hour, and generally 35 miles (56.3 km.) per hour.

The Reading Co. and the Delaware and Hudson Co. limit the speed, in terms of miles per hour, to twice the crossing (frog) number, and the London and North Eastern Railway specifies the speed restriction by means of the following formula :

$$V \text{ miles/hour} = 2.092 \text{ N},$$

where

N = crossing frog number.

The maximum speed on the lead curves, allowed by most Railways in India and South America, is 10 miles (16.1 km.) per hour or so.

Thus the train speed on the lead curves is very restricted, and high-speed operation is checked to a large extent. Therefore the tracks should be arranged so that no trains should run at high speeds over lead curves.

When a high-speed train has to pass through a lead curve, the radius of the latter should be as large as possible. Few railways prescribe different speed restrictions for facing and trailing points; some of them restrict the speed only when the train passes through non-interlocked facing points or spring points.

2. Minimum radius of switch lead curves.

As has been mentioned, the radius of the lead curve of turnouts over which high speed trains are operated must be as large as possible, i.e. large frog numbers must be used. In the intermediate stations where high-speed trains pass through, turnouts whose frog numbers are less than No. 16 should be particularly avoided.

The A. R. E. A. recommends Nos. 16 to 20 crossing numbers for switches and crossovers on the running roads carrying high-speed traffic. The Reading Co., the Chicago, Burlington and Quincy RR., the Great Northern Ry. and the Pere Marquette Ry. No. 20 crossings on track for high-speed operation, and the radius of the lead curve varies from 3 322′ to 3 434′ (1 013 to 1 045 m.). The New York, Chicago and St. Louis RR. and the Illinois Central RR., adopt the No. 18 crossing and a lead curve of 2 584′ and 2 864′ (788 m. and 873 m.) maximum radius respectively. The Northern Pacific Ry., the New York, New Haven and Hartford RR., the London and North Eastern Ry., and the Canadian National Rys. adopt a No. 16 crossing and its lead curve is about 2 000′ (609 m.) in radius.

The Japanese Government Rys. use the No. 16 simple switches (radius of lead curve 527 m. = 1 729′) or No. 12 symmetrical double switches (radius of lead curve = 502 m. = 1 647′) for high-speed track, and admit No. 12 simple switches (lead curve of 243 m. = 797′ radius) only at the terminals. But they also use No. 16 crossings at terminals where electric vehicles are frequently operated and arrive or depart at high speeds.

The type of crossing used should be adapted to the train speed. Generally speaking, at the entrance of a terminal, switches must be used with larger crossing numbers than at the exit, and in the intermediate stations where high-speed trains run through the crossing number should be larger than at terminals.

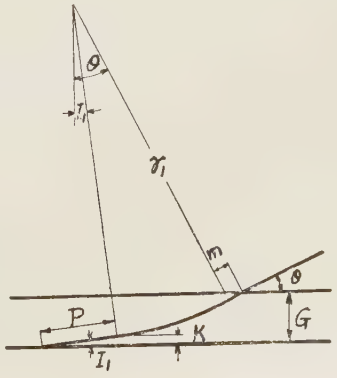
3. Tongue rails.

(1) Length and incident angle of switch tongues.

Stub switches are not used on high-speed lines, but split switches are used by almost all railways.

As the tongue makes a certain amount of incident angle with the stock rail, the high-speed train suddenly changes its

Fig. 34.



direction at the toe of the tongue and osciliates severely at this point. The incident angle must be as small as possible to ensure good riding.

In Figure 34,

$$I_1 = \sin \frac{K}{P}.$$

wherein

K = sum of the width of flangeway at the heel of the rail and the width of the top of the rail,
P = length of the tongue,
I_1 = incident angle.

As shown by this equation, the length of the tongue must be long in order to decrease the incident angle. All Railway Administrations favour long tongues for switches in main lines. The longest is 45′ 0″ (13.716 m.) and the most usual 30′ (9.144 m.) long.

If r_1 represents the radius of the switch curve, then

$$r_1 = \frac{G - (P \sin I_1 + m \sin \Theta)}{\cos I_1 - \cos \Theta},$$

wherein

G = gauge of the track,
Θ = angle of crossing,
m = distance between the theoretical point and the toe of the crossing.

When the value of Θ is constant, the radius of the lead curve becomes smaller as the incident angle decreases; therefore the crossing angle Θ must be decreased as I decreases, to enable smooth operation, i.e. long tongue rails must always be combined with crossings of large number.

When long point rails with small incident angle and large crossing numbers are used, the wear of rails diminishes remarkably. Experiments carried out in the most heavily loaded electrified line of the Japanese Government Rys. have proved that the amount of tongue wear of a No. 16 switch is only 1/3-1/5 of that of a No. 12 switch, and the wear of the lead rail of the former is about 1/7 that of the latter.

In the United States most Railways use No. 18 or No. 20 crossings with the tongue 30′ (9.144 m.) long and few Railways adopt tongues shorter than 24′ (7.315 m.). The incident angle is consequently small and 0° 57′ 18″ is the most common. A tongue 45′ 0″ (13.716 m.) long with an incident angle of 0° 22′ 0″ adopted by the Pennsylvania Railroad is the longest reported.

In Great Britain the Southern Ry. uses a tongue 40′ 6″ (12.344 m.) long, the London, Midland and Scottish Railway 33′ 6″ (10.211 m.), and the Great Western Railway 32′ 0″ (9.754 m.), combined with a No. 20 crossing, the angle between tongue and stock rail being 1/90 (Θ = 0° 38′ 0″) or 1/80 (Θ = 0° 43′ 0″). The London and North Eastern Ry. uses a tongue 28′ 6″ (8.687 m.) long and the Great Southern Railway 24′ 0″ (7.315 m.), with a No. 16 crossing, the incident angle being 1/64 (Θ = 0° 55′ 0″).

Until recently, the Japanese Government Railways have used in their main lines a tongue 5.486 m. long, its incident angle being 1° 23′ 21″, combined with a No. 12 crossing, but it was proved that even these points and crossings were not sufficient for modern high-speed trains, and curved tongues 6 m. (19′ 8 1/4″) long combined with a No. 16 crossing were adopted.

When a curved tongue is used, the radius of the switch curve may be increased and the incident angle of the tongue rail decreased as desired. But if the angle is too small, the toe of the tongue becomes very thin and is liable to fail under the blows from the wheels; therefore a certain amount of incident angle is indispensable.

The incident angle of the newly designed curved tongue of the Japanese Government Rys. is 0° 47′ 49″, and the results are quite satisfactory.

As shown in Figure 35, when curved tongues and a curved crossing are adopted, the radius of the lead curve is given by the following formula :

$$r_2 = \frac{\left(G + \frac{K}{2}\right) + \sqrt{\left(G - \frac{K}{2}\right)^2 + \frac{P^2}{2}(\cos I_1 - \cos \Theta)\cos I_1}}{2(\cos I_1 - \cos \Theta)},$$

Fig. 35.

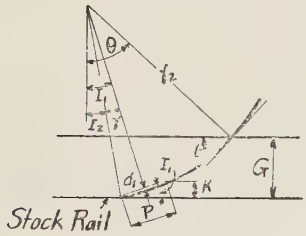
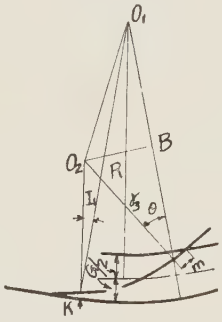


Fig. 36.



and the incident angle :

$$I_2 = I_1 - \frac{P}{2r_2},$$

In the case of a No. 10 switch built of 50 kgr./m. rails, of the Japanese Government Rys., substituting the numerical values :

$G = 1.067$ m.
$P = 5.000$ m.
$I_1 = 1° 36' 16''$
$\Theta = 5° 43'$
$m = 1.855$ m.
$K = 0.140$ m.

we get

$r_1 = 162$ m.
$r_2 = 221$ m.

or

$r_2 = 1.36\ r_1$
$I_2 = 0° 57' 20''$.

It may be seen that, by the adoption of curved tongues and curved crossings, the radius of the lead curve may be increased by 36 % and the incident angle reduced to 60 % of the value of the switch with straight tongues and crossings.

A curved tongue is especially recommended for the switch branching off a curve. If straight tongues and a straight crossing are laid in the case of a switch branching off inside a curve, not only the radius of the lead curve but also the radius of the main track become quite small, and high-speed operation of trains cannot be permitted in such a case.

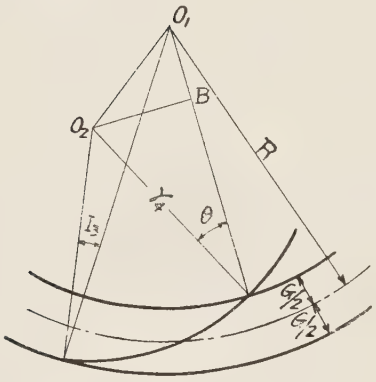
Now, when straight tongues and a straight crossing are used for a switch laid in a curve of radius R, as shown in Figure 36, the radius of the lead curve is :

$$r_3 = \frac{\left(R + \frac{G}{2} - K\right)^2 - \left(R + \frac{G}{2} + m \sin \Theta\right)^2}{2\left[\left(R + \frac{G}{2} - K\right)\cos I_1 - \left(R - \frac{G}{2} + m \sin \Theta\right)\cos \Theta\right]},$$

and when curved tongue rails and a curved crossing are used as shown in Figure 37, it becomes :

$$r_4 = \frac{\left(R - \frac{S}{2}\right)(G + S)}{\left(R + \frac{G}{2}\right)\cos I_3 - \left(R - \frac{G}{2} - S\right)\cos \Theta},$$

Fig. 37.



where

S = gauge widening.

Substituting :

R = 400 m.
G = 1.067 m.
I_1 = 1° 36′ 16″
I_3 = 0° 57′ 20″
Θ = 5° 43′ 0″
S = 10 mm.
K = 0.140 m.
m = 1.855 m.

we get

r_3 = 115 m.
r_4 = 143 m.

or

$r_4 = 1.24\ r_3$.

And in the case of a switch with straight tongues and a straight crossing, the radius of the main curve between the heel of the tongue and the toe of the crossing is decreased to about 200 m. Moreover the curved type of tongue and crossing have the advantage to enable the main curve to have uniform gauge widening and superelevation throughout their whole length.

(2) Section of tongue rails.

All Railways in Great Britain, Dominions and Colonies, countries in Asia and the United States machine tongues from the ordinary rail section as shown in Table 25. At the heel, the tongue has the same section as the stock rail, but along half of its total length, making contact with the stock rail, parts of the head and foot of the tongue are usually planed off, and in the case of flat-bottomed rails the foot of the tongue is thinned down so as to be housed above the foot of the stock rail.

Therefore the tongue machined from an ordinary rail section has not sufficient strength to withstand heavy loads moving at high speeds.

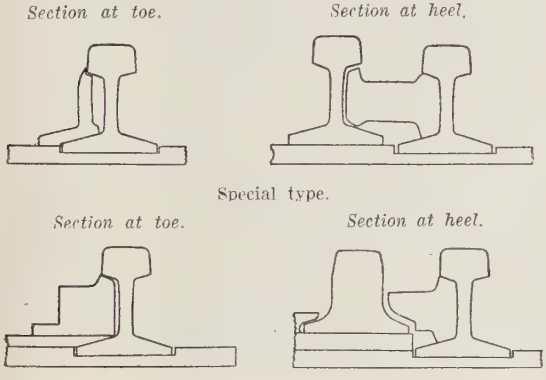
In the case of the bull-headed rail, the top of the tongue is at the same level as the stock rail and is supported directly by a chair, but in the case of the flat-bottomed rail the top surface of the tongue is higher than that of the stock rail by about 1/4″ (6.4 mm.) and its surface is tapered down from the middle to the toe, to a slope of from 1/100 to 1/200, so that the top surface of toe of the tongue is about 1/2″ to 5/8″ (12.7 mm. to 15.9 mm.) lower than that of the stock rail. The wheel load is supported by the stock rail at the toe of the tongue, but is supported by the tongue only in the part near the heel. Thus, not only is the section of the tongue rail insufficient, but it is merely supported by the stock rail on an inclined surface,

and therefore it is very unstable under loads.

In the case of the tongue in the 50-kgr. (100 lb. p. yd.) track used by the Japanese Government Rys. the difference in the level of the rail surfaces amounts to 10 mm. (3/8″), and this causes the severe oscillation of high-speed trains. In order to prevent such oscillation, a tongue, the top surface of which is at the same level as that of the stock rail has been designed and used experimentally, in combination with a movable crossing. The results are satisfactory. At the speed of 80 km. (50 miles) an hour, the maximum amplitude of vertical oscillation of a coach is reduced by 12 %, the maximum deflection of the equalizer springs by 15 to 34 %, the stress in the stock rail at the toe of the tongue by 13 to 21 %, the rattling noise within the coach by 3 %, and the noise outside the coach by 11 to 14 % respectively, as compared with a switch of ordinary design.

In order to increase the strength of the tongue made from an ordinary flat-bottomed rail, the Japanese Government Rys. have designed a tongue made from a special type of rail specially rolled for the purpose, as shown in Figure 38. This tongue is for a switch in 50 kgr./m. track; its height is 27 mm.

Fig. 38. — No. 10 switch for 50-kgr./m. rails.



(1 1/16″) below that of the ordinary rail section, but its sectional area is 92.9 sq. cm. while that of the ordinary one is 64.3 sq. cm., the former being larger than the latter by about 45 %. Moreover the tongue has a uniform curvature, equal to that of the lead rail throughout its whole length. Its top surface is at the same level as the stock rail and it is placed on a specially designed base plate. Thus, the stability of the tongue under loads has been remarkably increased. Field experiments upon this special type of tongue combined with a movable crossing have given satisfactory results. The improvement of the whole of the tongues in high-speed track on similar lines has been planned.

Tongues are generally made of carbon steel; however when the wear is heavy, manganese, chrome or heat-treated carbon steel are often used with good results. It is good practice to machine tongues from rails specially rolled, and lay them at the same level as the stock rails. Even when made from the ordinary flat-bottomed rail, it is desirable to so shape the tongue that the top surface is at the same level as that of the stock rail. With the bull-headed rail this is easily done, but with the flat-bottomed rail planing off the top surface reduces the stiffness. It is necessary to make the slope of the tapered part of the top surface of tongues flatter than 1/200 and so design it that the wheels run on the part with sufficient sectional area.

The Japanese Government Rys. have hitherto used tongues shorter than 5.50 m. (18′ 1/2″) with a surface inclination of 1/100, but recently designed curved tongues 6 m. and 6.5 m. (19′ 8 1/4″ and 21′ 4″) long, the slope being 1/212 and 1/250 respectively for the track carrying high-speed trains.

4. Crossings.

A wheel with conical tread makes contact with the wing rail of the crossing at the part of smaller diameter and with

the nose at the part of larger diameter. Therefore the wheel is depressed when it runs over the wing rail and then returns to the original height at the nose. In the case of a high-speed train this process is performed during quite a short time, even in 1/10 second; consequently the rolling stock sustains violent blows. The acceleration of the vertical oscillation increases as the crossing angle of the wing rail increases, or as the crossing number decreases. Moreover the radius of the lead curve becomes larger as the crossing number increases. The number of crossings to be used in the track for high speed operation must be larger than No. 16. In Great Britain and the United States, a number of Railways adopt No. 20 crossings. On the other hand, if the crossing angle is made too acute, there is the danger of a wheel taking the wrong line. In this case the movable crossing is used in place of the ordinary rigid crossing. The merits of a movable crossing are as follows :

(1) It gives a continuous running surface and has no gap between wing rail and nose;

(2) the crossing may be curved to suit the radius of the lead curve, and the gauge be widened according to its curvature;

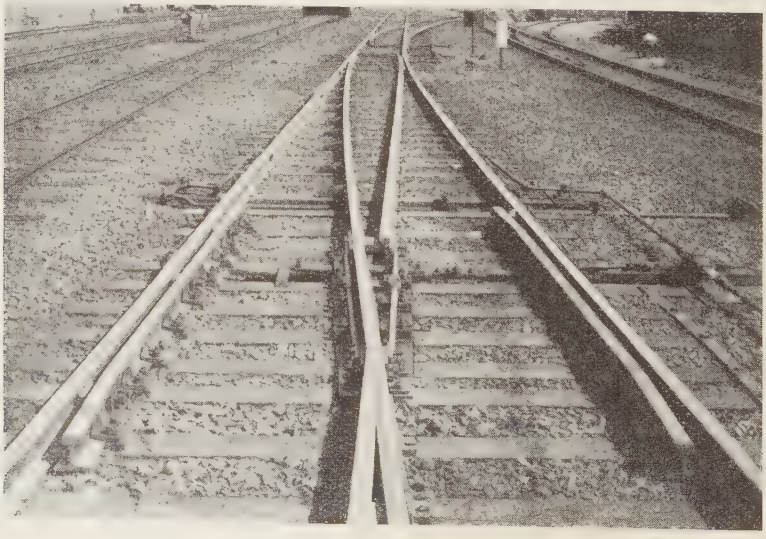
(3) the oscillation of rolling stock is reduced, and maintenance work on the crossing is made easier.

At the V-piece of a rigid crossing, widening of the gauge cannot be allowed ; therefore the widening given to the lead curve must be reduced on a short distance near the toe of the crossing. But in the case of a movable crossing, the lead curve may be extended throughout the crossing and uniform gauge widening given ; thus the movable crossing very effectively improves the running conditions of the high-speed trains.

Therefore the movable crossing is used by many railways although its cost is high and it requires a special device to interlock with the tongue. But in cold districts the throwing over is often checked by frost or other reasons.

There are two types of movable crossing, one with a movable nose, and an other with a movable wing rail; the movable-nose type adopted by the Japanese

Fig. 39. — Movable switch, Japanese Government Railways.

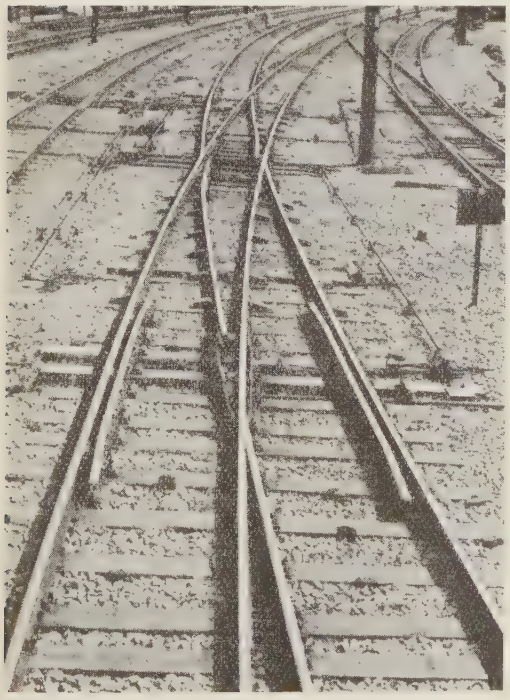


Government Railways, as shown in Figure 39, is giving good results.

The rigid crossing built from ordinary carbon steel rails would soon wear off at its wing rail and nose. Manganese steel crossings can often prove economical on lines carrying heavy traffic, but owing to their comparatively higher cost, railways in the U. S. A. rather adopt rail bound manganese steel crossings or crossings with a manganese steel piece only at the centre part, where wear is heaviest.

Diamond crossings are the most difficult to maintain and cause much noise and vibration in the rolling stock passing over them. The Japanese Government Rys. use a movable type of diamond crossing as shown in Figure 40; all the gaps in the running surface being eliminated, satisfactory results are obtained from it.

Fig. 40. — Movable type diamond crossing. Japanese Government Railways.



5. Guard rails and other accessories.

Wheels must be led by the guard rail a sufficient distance to prevent a violent lateral blow and avoid the risk of running unto the wrong line. But when the guard rail is too long, it will be struck several times by the back surface of the inner wheel when a locomotive with comparatively long rigid wheel-base passes over the switch, and the wheel is apt to override the rail owing to the friction set up. Therefore the length of guard rails must be determined according to the design of the rolling stock operated on that section. Consequently long guard rails may be used only when the crossing number or the radius of the lead curve is large.

Most Railways use guard rails shorter than 16′ (4.897 m.) with No. 16 to No. 20 crossings; however, the Delaware and Hudson Co. uses 20′ (6.096 m.) guard rails, the London and North Eastern Ry. and the London, Midland and Scottish Ry. 18′ 3″ (5.563 m.) and 18′ 0″ (5.486 m.) respectively, and the Great Western Railway 20′ 6″ (6.248 m.).

The Japanese Government Rys. use guard rails less than 2.740 m. in length in the case of rigid crossings, but the guard rail is 5 m. (16′ 5″) with movable crossings in order to protect the whole length of the movable rail, which is 2.125 m.-2.600 m. (6′ 11 11/16″-8′ 6 3/8″) long.

If the ends of guard rails are bent too much, wheels are liable to strike it heavily and cause oscillation of the vehicles. The A. R. E. A. specifies the slope of the bent ends of guard rails 16′ 6″ (5.029 m.) long to spread 3/4″ (19.1 mm.) on a distance of 3′ 2″ (965 mm.) or at the rate of about 1 : 50.5. In Great Britain, rates of 1 : 18 and 1 : 24 are the largest.

The 2.740 m. (9′) long guard rail used by the Japanese Government Rys. di-

verges at the rate of 1 : 21, and the newly designed 5-m. (16′ 5″) guard rail for movable crossings 1 : 42. The flangeway clearance should be decided to suit wheel design. On most railways the width is from 1 3/4″ to 1 7/8″ (44.5 to 47.6 mm.). When it is too wide there is danger of the vehicle running unto the wrong line, but when it is too narrow the wheel would be heavily drawn to the guard rail and the increased lateral pressure would result in rough riding and wear of the guard rail.

Adjustable guard rails designed by the Japanese Government Rys. may be displaced towards the stock rail as their side is worn, their life being thus prolonged. The switch curve has no superelevation, nor is the full amount of gauge widening provided in spite of its smaller radius. The gauge is apt to be widened at the toe of the tongue and narrowed at the point of the crossing. Therefore the stock rails and the lead rails of a switch should be rigidly fastened to sleepers by means of sole plates, bolts or coach-screws, and by means of rail braces if necessary.

Rail braces on both sides of the lead curve are gradually replaced by sole plates, and rarely adopted at present. Most Railways in the U. S. A. fasten the rail and sole plate to the sleeper with dog spikes, and the railways in other countries use coach-screws. In Great Britain, where bull-headed rails are used, the chairs are fastened to the sleeper with coach-screws or bolts.

6. Superelevation of a switch curve.

Generally speaking, it is difficult to give adequate superelevation to a switch curve, and even if it were provided with a certain amount of superelevation, riding conditions would not be much improved.

In the case of a simple switch, the surface of both rails at the tongue and crossing should be laid at the same level; therefore the superelevation of the switch curve, if any, must be run off in a short distance between the heel of the tongue and the toe of the crossing. If the superelevation ramp of the lead curve is to be made flat enough, the amount of superelevation cannot exceed a certain limit, or otherwise a switch of large crossing number should be adopted.

But in the case of a double switch, the crossing can be laid somewhat higher than the stock rail and the superelevation may be run off over a comparatively long distance beyond the crossing. The Japanese Government Rys. have designed superelevated double switches of No. 10 and No. 12 crossing numbers, with movable frogs; the superelevation is 20 mm. (25/32″) at the middle part of the lead curve, and is reduced at the rate of 1/400 towards the tongue and the crossing. The vibration of rolling stock on these switches has been proved to be less than in the case of switches without any superelevation.

In the case of a switch branching off the inside of a curve, full superelevation may be given to either the main curve or the lead curve or both if they carry heavy fast trains.

On the other hand, in the case of a switch branching off to the outside of a curve, when the branch line is to be superelevated, the outer rail of the main curve should be laid lower than the inner rail. Accordingly the trains which pass through the main curve must be operated at the lowest speed, or may be allowed to run into it after stopping in front of it.

When it is necessary to operate passenger trains on both the main and branch lines of a switch to the outside of a curve, it is better to give no superelevation at all.

It is advisable to avoid switches branching off from curves in the track carrying high speed trains, or at least to use curved points and crossings in unavoidable cases. At the same time, it

is necessary to give uniform superelevation throughout the whole length of such a curve on the side of the track on which the high-speed train is operated, to the detriment of another track.

7. Special turnouts.

It is not a good practice to adopt ordinary switches for catch sidings, emergency crossovers or sidings seldom used, as they cause violent oscillations of trains passing over them, and increase maintenance work and wear of the materials. Specially designed switches may be used for these purposes instead of ordinary ones.

The Japanese Government Rys. have designed two kinds of special switches to be used for such purposes. One is the continuous-rail derailing points, and the other the continuous-rail points.

The continuous-rail derailing points are laid at the ends of the arrival tracks in a station along a single-track line to lead overrunning trains into the catch siding.

As seen in Figure 41, each of the rails

Fig. 41. — Continuous-rail derailing point, Japanese Government Railways.

of the through line has continuous surface and lining and has no gap at all. Even if the through line is curved, the full amount of superelevation and gauge widening are given, corresponding to the radius, and to the speed of trains. In order to lead vehicles into the catch siding, the tongue which is laid at the outside of the stock rail and is mounted on the latter raises the flange of the tyre and thus allows it to pass over the stock rail. The surface of the outer lead rail is also elevated by 15 mm. (8/8″) at the crossing to make the rolling stock derail without severely damaging the stock rail.

Such a switch may be used only for a facing point to derail overrunning trains; it is impossible to run over it in the trailing direction from the siding, because the rail running surface of the siding behind the crossing is not elevated. The Japanese Government Rys. are now replacing all derailing points in the yards by the continuous-rail type.

The continuous-rail point is recommended for switches of emergency crossovers in the double-track line or sidings which are seldom used.

The principle on which the switch points are designed is the same as that

of continuous-rail derailing points as is seen in Figure 42. The outer lead rail is laid higher than the stock rail and the wheels passing through the switch curve run across the stock rail on their flanges and then roll down upon the ramp which is fixed to the running rail

Fig. 42. — Continuous-rail point, Japanese Government Railways.

of the branch line. Its characteristic is that vehicles would be able to freely pass through the switch from both directions. It is ascertained that all locomotives (steam and electric), wagons and carriages can pass it, without any danger of derailment, at a speed of 25 km. (15.5 miles) an hour. By the adoption of the continuous-rail derailing points or the continuous-rail points the weakest point of the main track can be eliminated, and it is recommended for points in track for high-speed operation.

8. Facing points in track for high-speed operation.

There is no difference in the design of the facing points and the trailing points. As a matter of fact the rolling stock oscillates more violently at the facing than at the trailing points at high speed, especially when the diverging angle of the tongue is large. The smaller diverging angle and longer tongue are most important for facing points taken by high-speed trains.

Steps should be taken to ensure close contact of the tongue with the stock rail. All railways adopt either mechanical or electrical locking devices. Facing points are usually locked by the lock bar or the track circuit controller.

Since the switch is a weak point in the track, and is one of the principal causes of rolling stock oscillation, it is required to minimize as far as possible the number used. Above all, the track layouts in which high-speed trains have to run over switch curves should be avoided. It is difficult to provide the lead curve with sufficient superelevation and gauge widening, and generally it has no transition curve at all, and it does not favour safe operation and smooth running of trains.

The radius of the lead curve should be larger than 500 m. (25 ch.) and the crossing number above No. 16 for an important switch in the running road. The diverging angle of the tongue should be reduced in inverse proportion to its length and it is desirable not to exceed 0° 50′ 0″. The Pennsylvania Railroad uses long tongues such as 45′ (13.716 m.), with a diverging angle of 0° 22′ 0″.

Tongues machined from ordinary flat-bottomed rails not only have insufficient strength, but have to be laid with their running surface higher above the stock rails. They are not suitable for high-speed track. To eliminate these evil effects, tongues should be made from special rails rolled for the purpose, and

provided throughout their length with the same curvature as that of the lead curve. The use of curved tongues is effective in increasing the radius of the lead curve too.

It is necessary to eliminate the gap at the crossings in order to minimize shocks to the rolling stock; the movable-wing crossing which is used by railways in the United States, and the movable-nose crossing used by the Japanese Government Rys. are giving satisfactory results in this respect.

The crossings are generally manufactured from ordinary rails, but on very busy lines cast manganese steel crossings or rail bound manganese crossings prove economical. For diamond crossings or slip points the movable frog should be adopted to improve the riding of fast trains. When switches branch off from a curved through road both the curvature and surfacing of the curve become quite irregular. Therefore such a track arrangement should be avoided as far as possible, and the adoption of curved tongues and curved crossings with regular superelevation should be considered in such cases.

Summary.

1. Weight of vehicles and operating speed.

The total weight of locomotives, carriages and wagons as well as their axle loads have gradually increased, and now a locomotive weighing 507 tons is operated. The maximum axle loads are 37.6 tons for locomotives, 24.5 tons for carriages, and 27.2 tons for wagons.

The maximum permissible speed of passenger trains on straight track is generally below 128.8 km. (80 miles) per hour, an a few Railways allow maximum speeds reaching 144.9 km. (90 miles) per hour.

The maximum speed of goods trains is generally 80.5 km. (50 miles) per hour, but some railways authorize a speed of 96.6 km. (60 miles) per hour.

On narrow-gauge railways the maximum speed of 95 km. (59 miles) per hour for passenger trains, and 65 km. (40.4 miles) per hour for goods trains authorized by the Japanese Government Railways are the highest of all; on other railways the train speeds are restricted within lower limits.

These maximum permissible speeds are still restricted on curved sections according to their radii, and railways in the United States restrict the speed according to the amount of superelevation provided.

The maximum speeds on falling gradients should correspond to the braking power of the trains, but most Railways specify no special speed restrictions for the down gradients except for extremely steep gradients, since all of the trains are provided with powerful continuous air brakes.

2. Construction of track for heavy loads moving at high speeds.

(1) *Gauge.* — Widening of the gauge is necessary to ensure smooth running of locomotives with a long rigid wheel base over sharp curves. However, excessive gauge widening should be avoided because it increases the hunting motion of the vehicles. There is a tendency to use less gauge widening in curves, as far as conditions permit.

(2) *Minimum radius of curves and maximum gradients.* — Sharp curves and steep gradients are the chief obstacles to high-speed operation. The minimum radius of curves on through roads is usually 500 m. to 600 m. (25 to 30 chains). As a matter of fact, on the sharper curves, the full amount of superelevation corresponding to the highest speed cannot be provided, and consequently the speed must be restricted.

Curves, especially reverse curves, must

be extremely flat in order to avoid uncomfortable riding.

The maximum gradient on the main lines is generally flatter than 1 in 100 and some railways specify the maximum as 1 in 200.

(3) *Amount of the superelevation and length of the transition curve.* — It is desirable to provide all curves in main lines with sufficient superelevation for the high-speed trains operated upon them, but in special sections where low-speed passenger or goods trains prevail, this is not always advisable, since the wear of the inner rail becomes heavy and the risk of derailment of the low-speed trains to the inner side of the curves increases when the superelevation is excessive. In such a case, it is necessary to provide the curve with adequate superelevation for both the high and low-speed trains, and when the amount of the superelevation is not sufficient for the high-speed train, its speed should be restricted to preserve the comfort of passengers.

The length of the superelevation ramp of curves must be at least 700 times the amound of superelevation, and over 1 000 times this amount should be the standard.

It is advisable to lengthen the superelevation ramp (cant developing incline) in proportion to train speed.

The minimum length of the straight section inserted between the ends of the transitions of reverse curves is from 20 to 60 m. (66′ to 197′) at least.

(3) *Track stresses.* — The stresses in rails, fish-plates, sleepers, ballast and formation caused by train loads and the dynamic augments due to the train speed may be calculated by the theoretical and empirical formulæ established separately by the Special Committee on Stresses in Railroad Track of the A. R. E. A., and by the Japanese Government Rys. It is most important to make the track strong enough for the stresses never to exceed the limits of resistance of the materials under the heaviest loads at the highest speeds. If the track is not strong enough to bear the rolling stock at the maximum speed, the operating speed must be restricted accordingly.

It has been proved that the track stresses vary to a large extent with the wheel arrangement of the vehicles and the counterbalancing of locomotives. Consideration should be paid to the design of the vehicles to minimize the track stresses as far as possible.

4. Rails.

(1) *Weight of rails.* — The adoption of heavier rails is necessary not merely in order to safely withstand the stresses set up by the train loads and the destructive effect of the hammering, but also to reduce the oscillation of vehicles and effect large savings in track maintenance costs. Consequently, a number of Railways use a rail heavier than theoretically required. Especially in the United States, rails weighing from 112 to 130 lb. p. yd. (56 to 65 kgr./m.) are commonly used, and in other countries 50 kgr./m. rails.

(2) *Rail length.* — Formerly the standard rail length was 10 to 12 m. (32′ 9″ to 39′ 4 1/2″) and even the longest was 60′ (18.288 m.). But of late the methods of manufacture and transport have developed, and the theoretical and empirical studies regarding the buckling strength of long rails have permitted the use of rails 20, 25 and 30 m. (65′ 7 3/8″, 82′ and 98′ 5 1/8″) long, without any drawbacks. Welding of rail joints has been tried by various Railways with satisfactory results.

The standard length adopted by the Japanese Government Railways has been so fixed that the natural vertical oscillation of the various vehicles does not resonate with the forced oscillation due to the hammering at the rail joints.

An excessive joint gap shortens the life of the rail, but when it is too small

an appreciable axial force is apt to be set up in the rail. Heavier rails can well withstand the axial force due to the temperature rise, when the ballast is filled up sufficiently between the sleepers.

(3) *Welding rails.* — A few Railways have reported the use of extra-long rails obtained by welding together two or several standard lengths by the thermit-pressure process, satisfactory results being obtained. The Delaware and Hudson Co. laid a continuous welded length of 6 983′ (2 128 m.).

In the United States and Canada welding is resorted to for repairing battered rail ends rather than for reducing the number of joints. Both the gas and the electric arc welding processes are used in general, and each has its characteristics.

(4) *Canting of rail.* — With the conical wheel tread, the mean amplitude of the lateral oscillation is slightly increased as compared with the cylindrical tread, but a sudden ample oscillation does not occur with the conical tread, and the rolling resistance of vehicles over curved track is also smaller with the latter tyre; therefore almost all Railways use the conical wheel tread.

Accordingly, rails are generally laid on inclined bearing plates with a cant of 1/20 to 1/40 to match the taper of the tread.

(5) *Method to prevent the wear of rails.* — Rails of special steel, such as chrome, medium manganese and sorbitic steel rails are economical on sharp curves where rail wear is heavy.

Lubrication of the rails and wheel flanges very effectively reduces such wear, and at the same time decreases the rolling resistance.

5. Construction of rail joints.

The rail joint is the weakest point in the track and about half of the total tamping work is required for the joints. Reducing the number of rail joints by the use of longer rails or welding the joints is the fundamental remedy, but at the same time the joint itself must be made as strong as possible.

It is preferable to increase the sectional area of fish-plates than to increase their length, in order to strengthen them, but if they are properly designed, the maximum stresses in fish-plates of smaller area can be less than those in plates of larger area, but of less scientific design.

On track carrying high-speed traffic, the suspended joint is exclusively used, with the exception of a few railways in the United States whereon the supported joint is used.

As to the merits and demerits of opposite and staggered joints, opinions of Railway Administrations in the United States quite differ from those in other countries. On the whole, in the case of heavy rails laid on closely spaced sleepers staggered joints may be used, but in other cases where the track is not sturdily built, the use of opposite joints is advisable in order to save maintenance work and prevent rough riding.

Between rails shorter than 12 m. (39′ 4 1/2″) the gap width calculated theoretically may be given to the joint, taking into consideration the rail length and the highest temperature of the track, without regard to the constraining forces opposing free expansion. But the width of the joint gap between the longer rails is actually far smaller than the computed value, ignoring the resistance to expansion, and consequently very large axial stresses are set up in the rail.

In such a case, when the joint gap has closed up, removal of the ballast is liable ta cause buckling of the rails, and steps must be taken to prevent it.

6. Sleepers and bearing plates

The size and spacing of sleepers in track for high-speed operation must be such that they can withstand the weight of the vehicles and their speed.

The sleepers must be closely spaced whilst not hindering the tamping work, especially at the joints.

Sleepers should be made of good hard wood perfectly treated, and well resisting decay and mechanical tear under various conditions.

Bearing plates are indispensable on the track carrying heavy loads at high speeds, to protect the sleepers and maintain the correct gauge. But when their base area and the thickness are not sufficient, it is impossible to obtain satisfactory results.

Single-shouldered bearing plates are used only with dog spikes, and when coach-screws are employed, the use of double-shouldered bearing plates is recommended.

Many railways are still using dog spikes, but since coach-screws are superior to the former as regards holding power, they have been gradually taking the place of dog spikes on main-line track.

7. **Anti-creepers.**

Rail creep interferes with the width of joint gaps and has other evil effects on rails. Creep is mainly met with on track with light rails laid on a soft roadbed. It has been found that creep decreases to about 72 % when one anti-creep device is installed on each 10-m. rail length.

When several anti-creepers are to be installed on one rail length, they should be distributed uniformly along the whole length of the rail; which is more effective than concentrating them at some points.

8. **Rail braces.**

No railway uses rail braces on curves, except the Japanese Government Rys., who are however, removing the braces from main-line curves, bearing plates being used instead.

9. **Ballast.**

The nature of the ballast and its standard cross section should be decided taking into consideration the nature of the loads operated upon it. When the condition of the formation requires it, a layer of sub-ballast of the proper kind should be used.

The solid roadbed laid in a long tunnel, etc., is effective in reducing maintenance work, but a proper design of solid roadbed adapted for main-line track should be further investigated.

In the case of the soft roadbed, a concrete slab of suitable depth laid under the ballast is proving satisfactory.

10. **Modernising old track.**

All Railway Administrations are improving their old tracks in order to operate high-speed trains safely and comfortably.

Sharp curves are the greatest obstacle to high-speed operation; curves sharper than 600 m. (30 chains) radius should be avoided in main lines, because it is difficult to provide them with the super-elevation to suit the highest speed.

When a switch is laid in a curve, not only the radius of the lead curve but that of the through road becomes quite small, and results in an irregular rail surface. In such a case, it is necessary to restrict train speed severely. The use of curved tongues and crossings instead of the ordinary type will improve conditions.

The mechanical strength to safely withstand the impact and lateral thrusts from heavy loads moving at high speeds and keep the maximum track stresses within the range of the allowable limits for the materials used is the greatest requisite for modern track.

The linear weight of rails, spacing of sleepers and depth of ballast have marked influence upon the strength of the track as a whole and consequently upon track maintenance cost. In particular

heavier rails are most essential for track carrying heavy and fast trains.

11. Switches.

Switches have defects inherent to their design, the irregularity of the running surface and alignment being the chief causes of rough riding; accordingly speed restriction over switches is inevitable.

Usually No. 16 to No. 20 crossings (frogs) are used for facing points in main lines.

In order to increase the radius of the lead curve it is most desirable to reduce the incident angle of the tongue rail and the crossing angle as far as possible and further use curved tongues and crossings.

As to the tongues, in the case of flat-bottomed rails they have been manufactured from ordinary rails hitherto, but of late heavy sections specially rolled for the purpose have come into general use.

Rigid crossings cause violent oscillation of vehicles even when perfectly maintained. For important switches and diamond crossings on high-speed track, the use of movable crossings, either with movable wing rail or with movable point rail, is to be recommended.

In the case of a double symmetrical switch some superelevation can be given, and when a switch is laid in a curve the full amount of necessary superelevation should be provided on the principal side of the curves over which fast trains run, whether it be the through road curve or the switch curve.

For switches of catch sidings and emergency crossovers, it is advisable to use continuous-rail derailing points or continuous-rail points to prevent oscillation of high-speed trains and minimize wear and tear of track materials.

[621. 33]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

13th SESSION (PARIS, 1937).

QUESTION VI.

Methods and devices used, in connection with electric traction, to save current between the supply side of the power station and the driving wheels (feeders, substations, tractors), and in particular the use of mercury rectifiers.

REPORT

(Switzerland, France and Colonies, Spain, Portugal and Colonies, Italy, Belgium and Colony, Luxemburg, Netherlands and Colonies, Egypt),

by Mr. EGGENBERGER,

Ingénieur en chef de la Division de l'Électrification, Swiss Federal Railways.

and Mr. ECKERT,

Chef de section (same Administration and Division.)

Foreword.

The choice of the site of the power stations and the type of current to be used ought to be counted amongst the methods required to reduce current consumption. These two subjects have been included in the main question : « Railway Electrification from an economic point of view » and were dealt with in Question V at the 12th Session (Cairo, 1933).

Thus they have already been discussed and we will not go over them again but will consider them as limiting the scope of the question we have to examine.

The reports which have already been presented on railway electrification from the economic aspect show, amongst other things, that when a line is electrified an endeavour is made to save coal, either by using available water power or by using the coal in central power stations, and that the very great capital investment involved in railway electrification makes it necessary to reduce the operating costs very substantially in order to meet the interest and amortization charges. This aphorism shows the capital importance of the cost of energy in the finances of electrical working. Consequently, it may well be said that, as the working costs have to be kept down, every known financial or scientific method available and applicable at the time the railways are electrified is being used to bring down the current consumption.

The search for the most economical solution at different periods of technical development has naturally led to different systems of traction being adopted. Consequently, all steps and devices by which energy consumption can be reduced cannot be of general application; such methods are not in all cases and to the same degree an economical remedy. Some of them would even effect no economy whatever, owing to the high cost of altering the old plant still in good working order and meeting service requirements.

As our report cannot cover all details, we propose to limit it to examining the devices and measures to be adopted in electric traction to effect economies in current consumption and to studying the proportion in which they have been and are being resorted to.

To this end the Reporters drew up a questionnaire on these lines, and we would like first of all to thank the Administrations who have been good enough to reply to it. When arranging the replies in table form we have not had any intention of making comparisons which would be far from complete, but have tried to ascertain from them the economic relation between the application of measures and arrangements which might save current and the results therefrom.

A. — General considerations.

By steps to be taken and devices to be used to effect savings in electric traction, we mean all those which, when adopted, reduce losses in the distribution, transformation, conversion, and utilisation of the electric energy and, reduce train resistance.

These are thus measures and devices of an inherently electrical kind, and in particular in electric traction, and others of a mechanical nature, which are of value in all undertakings endeavouring to effect, not only current savings, but also fuel economies.

By reason of the economic principles which govern railway operation as a whole, measures are continually being taken and equipment installed to save current and fuel as improvements have been introduced and technical knowledge increased. We will not deal with those sufficiently known. Moreover, as we cannot speak for the future, we must be satisfied to review the measures and equipment now being investigated theoretically and experimentally in the endeavour to procure further savings of current and develop electric traction.

Amongst these measures the use of mercury vapour rectifiers holds the first place. The continual improvement in these appliances and the definite results so far obtained have revolutionised electrotechnics and given a new direction to the solution of electric traction problems. Naturally therefore the question deals in particular with the use of such rectifiers.

In view of the great interest taken in such rectifiers we think it desirable to give a brief elementary idea of their construction and working before considering their use in electric traction work, and the experiments made with them. We feel that such a description, however incomplete, will make the conditions under which they work in service more easily understood.

Mercury vapour rectifiers.

(MUTATORS).

1. *General.*

Mercury vapour valves are so described through their method of working and their use as rectifiers. They were used formerly exclusively to convert alternating current into direct current. Their ordinary property is known : the mercury vapour valves inserted in an alternating current circuit allow positive cur-

rent to pass from the anode to the cathode and hold back the negative current. In the proper meaning of the words mercury vapour rectifiers are not, rectifiers, but electric valves. The possibility of controlling the starting of mercury vapour arcs by means of polarised grids has extended the application of these valves not only for converting alternating to direct current but also to change the frequency and to convert direct current into three-phase. The need then arose for an adequate definition of these valves and new names such as « convertor, alternator, undulator, diverter, modulator, ionic valve, and mutator », were put forward. The neologism mutator from the latin « mutare » (to change, vary, transform) appears to be the best although not yet generally used, and we have adopted it in this report to avoid too long and too indefinite expressions.

The first application of the mutator for converting three-phase to direct current was made some thirty years ago. These mutators, however, have only reached their present foremost position in electric traction within the last fifteen years.

2. *Description.*

The action of the mutator is due to the property of mercury of forming, in a rarefied atmosphere, a focus for the emission of electrons.

In principle the mutator consists of a sealed glass or iron container with the cathode, formed by the mercury, in the bottom and at the top the anodes insulated from the walls.

The mercury in the cathode vaporises under the electric arc and condenses on the walls of the container to return as a liquid to the cathode. The cathode is thereby regenerated continually and does not become exhausted.

The anodes are made of more highly refractory materials, such as graphite.

The vacuum in the container is as much as 10^{-5} to 10^{-6} mm. of mercury. The pressure of the mercury vapour is determined by the temperature of the condensing surfaces and varies between 10^{-3} and 10^{-1} mm. of mercury.

The provision of polarised grids is the new feature in mutators. Like the anodes the grids are made of vaporisation-resisting material, such as iron, are insulated from the walls, and are arranged in front of each anode. There are therefore in each mutator as many grids as anodes. The grids are inserted in an independent direct-current circuit on the cathode. By suitable variation of the polarising current, the grids can be made positive or negative at will, relatively to the cathode.

3. *Physical basis.*

We cannot develop here the complex theory of the electric discharge in low pressure gases or vapours, on which the working of mutators depends, but only summarise the fundamental principles on which they work.

Mercury vapour composed only of electrically neutral atoms would be insulating; for it to let current pass when subjected to a potential difference it must contain load carriers, ions or electrons by means of which the current is carried.

Each electrically neutral atom can produce a positive ion and an electron. The electrons are the elementary loads of negative electricity, by virtue of which a current can pass through a conductor. A positive or negative ion is an atom which has lost or attracted an electron; neither can carry current in the exterior circuit.

The electric arc consists of various discharges which in an ionised atmosphere are capable of carrying considerable currents under a small static field.

The discharge is single pole when the current is carried solely by the elec-

trons produced at one of the electrodes, and certain discharges cannot exist unless their electrodes are given a definite polarity.

One of the properties of mercury is to become, in an electric arc, a focus of emission of electrons in unlimited quantity when the mercury electrode is connected to the negative pole of the current supply i.e. when it forms the cathode. This focus of emission concentrates itself as a luminous area which moves about on the surface of the mercury. The expulsion of cathodic electrons from a mercury vapour arc is mainly the effect of an intense field of the order of 10^{-6} volts/cm. present before the cathode and is only facilitated by the more or less great heating of the cathode, as the mercury vaporises before attaining a high enough temperature for the electronic emission to become important. The voltage drop in the cathode zone being only 10 volts, this zone formed by a concentration of positive ions is of small width.

The positive column, in which the carriers of each sign are almost equal in number, extends from the limit of the cathode zone to the anode. There is a uniform pressure drop of 8 to 15 volts along this column, directing the electrons towards the anode and causing sufficient ionisation to make good the losses in positive ions taking place along the column. The anode extending into this column collects the electrons required to carry the current and causes a voltage drop of 2 to 8 volts. The total voltage drop across the arc does not exceed 20 to 30 volts.

The vacuum has to be very complete to prevent the residual gases from giving birth to positive ions in sufficient number for the electronic discharge to lose its character of unidirectional discharge.

The temperature at which mercury vapour condenses determines the pressure of the vapour; it plays a very important part because excessive pressure gives rise to a superionisation which induces backfires, and insufficient pressure increases the voltage drop in the arc.

The polarised grid is an auxiliary electrode and has no influence on the surrounding medium when its potential is that of the medium. If, however, it is given a negative potential relatively to the cathode it will develop about itself a field which repulses the electrons, and thus opposes the passage of the electrons from the cathode to the anode. A negative grid therefore can impede the ignition of an electronic discharge; it cannot quench an arc once lit because the grid is then in a very dense field of carriers, on which its field of action is too restricted to oppose the passage of the electrons towards the anode.

4. *Design of mutators.*

The mutator with glass bulb was the only design for a long time. For small powers it is simple and reliable. The glass bulb is an insulator which resists the action of the mercury vapour and is perfectly tight even where the conductors are taken through it. The vacuum inevitably falls slowly and the bulbs have to be renewed periodically. Glass mutators are still manufactured for continuous rating at 500 amperes. The life of these bulbs in continuous traction service exceeds 25 000 hours. The two difficulties in increasing the capacity of glass bulb mutators are sealing the passages for the large-dimension conductors and cooling the bulb.

To overcome these difficulties the makers have introduced the metal tank, the vacuum being maintained by a set of pumps consisting of a preliminary-vacuum pump and a high-vacuum pump. Such progress has been made in the manufacture of metal mutators that the voltage drop of the arc is less than in the glass bulb mutator, and the reliability is greater. The metal tank is artificially

cooled by water or forced ventilation. The life of the metal mutator is unlimited and largely balances the drawback of having to instal a set of vacuum pumps.

The capacity of the metal mutators built for electric traction has now reached 3 000 kw. under constant load and in the case of mutators working at 4 000 volts D.C. this output can be increased to 6 000 kw. momentarily without any ill effects. Mutators for direct current voltages of 12 000 to 22 000 are already in use in radio transmitting stations. The Brown-Boveri Company has perfected a single mutator for 50 000 volt direct current and a capacity of 2 000 kw. under continuous working conditions. This shows that the 3 000 to 4 000-volt direct current adopted for electric traction offers no difficulties and that we may expect the voltage of 50 000 to be exceeded.

The arc is induced in the glass bulb mutator by an auxiliary anode arranged laterally close to the cathode, and in the metal tank mutator by a movable auxiliary anode or by positive impulses on the grids.

The *grid control* systems may be classified in three groups :

a) synchronous switches by means of which the grids are connected in turn to the positive and to the negative poles of a direct current supply;

b) induction devices by means of which the amount the alternating voltage on the grid is out of phase can be varied relatively to the voltage of the current fed to the anodes;

c) devices for altering the form of the tension applied between grid and cathode to displace the ignition point.

All high-power mutators working on a three-phase network as a current or phase converter are six-phase.

When the voltage and current are required to be perfectly corrected reactors and capacitors are inserted in the converted current circuit.

5. *Working of the mutators.*

The *voltage drop* in the mutator itself increases very little with the length of the arc and is therefore more or less the same for all voltages; it varies from 20 to 30 volts.

In the 1 500 to 3 000-kw. mutators the *auxiliary losses* due to the excitation, the preliminary and high-vacuum pumps and the vacuum measuring devices, are about 2.7 to 3 kw.

The artificial cooling by water circulating pumps and fans absorbs some 0.2 % of the nominal power. The auxiliary losses being relatively low, the *efficiency* of the mutator is mainly a function of the working voltage; it increases with the working voltage and reaches 98 % with traction current voltage.

The ideal working *temperature* for the mutator is between 45° and 55° C. (113° and 131° F.). They work reliably even at a minimum temperature of 15° C. (59° F.). Under an overload, the temperature should be increased so that the mercury vapour should be denser and consequently contain more charge carriers between the anodes and the cathode.

Back fires completely cut out the valve effect of the mutator; it is due generally to the formation of a cathode on an anode. Some causes of backfire are :

a) A rise in the mercury vapour pressure through excessive temperature in the tank or by an overload, or again by a cathode being formed on an anode;

b) Condensation of the mercury vapour on too cold an anode;

c) Vaporisation of the anode itself through too high a temperature;

d) Overvoltage occuring between an anode and some part of the mutator and causing a luminous discharge to degenerate into a return arc;

e) Metallic or alkaline impurities, traces of which on the anode emit electrons or produce gases inside the tank and therefore spoil the vacuum.

The *polarised grid,* as we have seen, enables the arc to be started, broken and unverted at will; this feature confers various direct and indirect functions on the grid.

The direct functions include :

a) The regulation of the direct-current voltage;

b) The breaking of short circuit currents, overloads, and accessorily the extinction of back fires.

a) The *voltage regulation* is obtained by a delayed ignition owing to which the positive half waves of the alternating current are no longer used at the actual maximum voltage but a lower value. The result is a reduction in the direct-current voltage, the more marked the more the arc ignition is retarded.

b) The *interruption of short-circuit currents and overloads* by polarised grids is effected by blocking the ignition completely. The method is very simple. By applying simultaneously and maintaining negative grid voltage, the arcs of the different waves naturally die out, when the corresponding positive half wave passes through zero and do not ignite again. Grid polarisation is controlled by an ultra-rapid excess-current relay, so that the complete interruption is not more than a period. It is therefore very fast; usually the cut-out is not affected and even if the short-circuiting current should bring it out the break takes place under no load. As soon as the overload disappears, the mutator automatically starts up again.

The indirect functions of the polarised grid have made it possible to use mutators in other directions than merely the transformation of alternating into direct current. It can be used to transform direct into alternating current, to couple up three-phase systems at different frequencies, and to transform three-phase into single-phase current.

a) *Transforming direct into alternating current.*

In electric traction, converting direct current into alternating current, enables regenerative braking to be resorted to at places where the regenerated power exceeds the load at certain times, and has to be absorbed entirely or partly by the three-phase system.

The function of the mutator is thus to allow the direct current from the overhead line to pass to the three-phase system. At such a time the direction of flow of the direct current is reversed. The mutator being unable to change its polarity has to be commutated. Through this commutation the mutator no longer works on the positive but on the negative frequencies of the alternating current. The direct-current voltage then having to overcome the voltage drop which increases with the current intensity, the regulation of the voltage by the mutator can be assisted by changing the ratio of transformation at the transformers.

The problem has been solved in practice, two main solutions being available for regeneration work.

1. Two groups of mutators are installed, one feeding the contact line and the other, of lower capacity, permanently acting as a direct-current to three-phase converter. The regeneration of energy on a railway being intermittent, for safe working the electrodes of the direct-alternating mutators have to be kept hot by keeping them under a constant low basic load. This artifice causes no difficulties and the losses are inappreciable as the energy in this basic load is returned almost entirely to the primary system.

2. The installation consists of two groups of mutators, the direct-alternating

group being reversible. By means of a reversing switch for each of the mutators of the group, the latter works alternatively as direct to alternating when regenerating, and as alternating to direct when the load is heavy. The change-over is controlled automatically according to the load of the permanent alternating to direct current group. This solution has made it possible to make more full use of mutators.

b) *Coupling up three-phase systems of different frequencies.*

Since it is possible to take and supply direct current from and to a three-phase system by mutators, two three-phase networks of different frequencies can be coupled together without difficulty by using as for supply and regeneration in traction equipments two groups of mutators either reversible or not according to whether the exchange of current has to be made from a given system to another or alternatively between two systems. This method of coupling has received several practical applications.

c) *Converting three-phase to single-phase current.*

Considerable progress has been made in this field and the problem may be considered as solved. The conclusive results obtained with the trial mutators have shown that single-phase 16 2/3-cycle current with perfectly sinusoidal voltage, due to the use of voltage and current equalisers can be drawn from a three-phase 50-cycle system. This method of conversion has not yet been adopted in practice, but this appears to be merely a matter of time.

The *loss in power factor* resulting from the action of the mutator on the three-phase system is insignificant with the normal point of ignition. The out-of-phase effect in this case is due to the residual excitation; it increases proportionally to the amount of retardation in the point of ignition required to regulate the voltage. This phase displacement causes no difficulty on the primary side, so long as the load resulting from the mutators does not preponderate.

The introduction of *extra-high-voltage mutators* has once again raised the problem of transmitting energy as high-tension direct current. This question also affects electric traction, seeing that the electrified railway systems are becoming more and more extensive, and the power transmissions more and more important. In the present-day state of this problem, there are still many difficulties to be overcome before a mutator absolutely reliable under the voltages and powers required for this purpose will be available.

Automaticity. — The simplicity and reliability of the mutator and the equipment for controlling and regulating the load, vacuum and temperature, are such that the equipment is very suitable for remote control and automatic operation.

Summary.

1. Of all the high-power equipment and machines so far introduced, the mutators are those which show the highest efficiency when converting alternating into direct or single-phase current and direct current into alternating current, or when changing the frequency of alternating current.

2. From the economic point of view, the high-power steel tank mutator, thanks to its unlimited life, has displaced the glass bulb mutator, as the latter has to be renewed periodically.

3. The ordinary metal tank mutators of constant power up to 4 000 kw. under 4 000 volts, of a momentary capacity of 6 000 kw., with polarised grids solely for breaking the short-circuit and overload currents, meet the requirements of railway working in all points.

4. The regulation of the voltage by

means of mutators with polarised grids, by retarding the ignition of the arc produces phase displacement which has no disadvantages so long as the load on the three-phase system due to the mutators does not preponderate.

5. The regeneration of the braking energy with direct current traction and the coupling up of three-phase systems at different frequencies are made possible with alternating to direct current mutators working in conjunction with reversible mutators.

6. The problem of transforming three-phase into single-phase current of different frequency by means of a mutator can be taken as solved. However, its practical application is still dependent on the solution of certain detail problems.

7. Great progress has been made in the design of high-voltage mutators; a voltage of 50 kV. and a power of 2 000 kw. so far reached on the test bed are still far too small for power to be transmitted over long distances by high-tension direct current transmission lines.

B. — **Power transmission lines.**

The quantity of energy used by a railway for traction purposes is proportional to the extent of the electrification and varies from a very small quantity such as 1.5 million kw./h. per annum up to the greater values, exceeding 500 million kw./h. per annum.

Two systems have been adopted for the primary distribution, namely the *independent system*, whereby the transmission lines are set aside exclusively for transmitting the traction current, and the *mixed system* in which the traction current and the industrial power are common and transmitted under a single form of current at high voltage by means of common lines.

In the case of small undertakings, the distribution problem is solved. Individual power production being out of question, the source of power supply and the transmission will be dictated by circumstances. If isolated, such undertakings will purchase their power from an industrial network, supplying a given kind of current; if they have some points in common with an electrified main-line railway, as a rule they will find it profitable to adopt the same traction system and take current from the main line railway Company's transmission system.

In the case of large railway systems, the problem is a different one according to the area covered and the lay-out of the railway system. The distribution system to be used, independent or mixed, depends on the power to be transmitted, the load fluctuations, and the transmission distances. In the case of a dense railway system the energy is used at traffic centres fairly close together, from which several railway lines branch off.

These centres show high loads and rarely lie on the route of an industrial transmission line of similar capacity. The regulations imposed on an industrial transmission system as to voltage regulation are very exacting, so that the considerable fluctuations of load due to the railway system can cause great difficulty. Contrariwise electric traction can tolerate momentary voltage variations between much wider limits, the range being the greater the rarer the peak loads. Railway transmission lines, therefore, can be used more fully and, in view of the short time the peak loads last, more economically without having to provide very costly voltage regulators.

The arguments which caused certain railways to produce the energy required in their own power stations are equally valid when applied to primary distribution networks. Although their power houses have to be included amongst the large power stations, transmission of the energy produced is over relatively short distances, and the high voltages requir-

ed in the case of large interconnected networks need not be used. Any railway which can absorb all the power it produces would need rather to be linked up with other power stations to complete its productive capacity. The transmission lines leaving its power stations can thus form self-contained lines which do not have to carry any appreciable additional load for industrial requirements.

Distribution conditions are very different on a large but strung out railway system. The power stations are farther apart, the distances the energy has to be transmitted are much longer, and the local loads much smaller. In other words an equal amount of energy is used over a much wider area. The industrial distribution networks, on the contrary, become increasingly important the farther apart the power stations, towns and industrial centres. The load on an interconnection due to industrial distribution being the major, there ceases to be any objection to a mixed distribution system, which becomes the most economical solution.

This conclusion is confirmed in the clearest way by comparing the joint electric working of the Paris Orléans-Midi (*P. O.-Midi*) System on the one hand and the *Swiss Federal* Railways on the other. The *P. O.-Midi* System, although 22 % greater than the *Swiss Federal* uses 13 % less energy annually. Per kilometre electrified the *Swiss* Railways use 33 % more energy than the *P. O.-Midi*. The primary transmission lines of the *P. O.-Midi*, on the other hand include 4 060 km. (2 523 miles) of 60 to 220-kV lines as compared with the 1 241 km. (771 miles) of 33 to 132-kV. lines of the *Swiss* Railways, i.e. only 30 % of the former. In other words, the *Swiss Federal* Rys. have a 35 % higher consumption factor and a 30 % smaller primary transmission system, or a total difference of 65 % as compared with the conditions on the *P. O.-Midi*.

The *energy losses and voltage drops* in the transmission lines vary from 1.9 to 8.5 % on the former and 2 to 15 % on the latter. The higher values are in lines only carrying traction current; the 15 % voltage drop must be considered an exceptional maximum.

As the whole of the energy in the primary lines is still transmitted in the form of alternating current, the energy losses are due partly to the reactive current and to the self-induction of the overhead lines or by the capacity of the underground cables. The inductive and capacity effects vary as the frequency of the current; consequently they are greater with the 50-cycle industrial current than with a 16 2/3-cycle traction current. Constant direct current having no inductive or capacity effects, all losses and voltage drops in the mains are due to the ohmic resistance of the latter and are consequently much smaller than when transmitting the same quantity of energy as alternating current over the same lines. Owing to this great advantage of direct current, the question of transmitting energy as high-voltage direct current was raised in the early days of electrotechnics. Although the high voltage mutator appears to have solved the problem, much development work will still be needed if the transmission of energy as high-voltage direct current may be expected in the near future.

The *reactive load* on the transmission lines is reduced when rotary converters are installed by using them as synchronous compensators. Synchronous compensators only have to be provided for this purpose when the mains, generators and transformers are overloaded. As a general rule, the energy saved by a reduction in the line losses is almost balanced by the power required to operate the compensators in question.

Condensers are used successfully as static compensators in low-voltage installations. Condensers for high volt-

ages, of the order of 15 kV. are now obtainable at reasonable cost, thanks to new manufacturing methods. As their compensating effect is a function of their capacity and therefore is constant, they do not adapt themselves to load variations in the line. In addition they must be used with care in high-voltage installations on account of the resonance they can set up therein. The efficiency of condensers is very high.

Savings in current can be made, on a closed transmission system fed by a number of power stations, by carefully distributing the active and reactive loads between the different power houses.

The losses by discharge at the insulators or by corona effect on the conductors when transmitting current at under 100 kV. pressure are insufficient to justify special measures apart from those required for safe working. When transmitting at 200-kV. the insulation has to be improved by increasing the number of elements of the chains of insulators, the potential has to be distributed over the chains of insulators by rings at both ends, and large-diameter cables, even hollow cables have to be employed. Such special measures may become necessary to reduce wireless interference.

Summary.

1. An independent distribution system meets the requirements of a railway owning large power stations, the load capacity of which is absorbed by means of one or more transmission lines.

2. The mixed distribution system is the better whenever the industrial load is the greater, and when the energy has to be transmitted long distances.

3. It is not yet possible to transmit energy in the form of high-voltage direct current over long distances so as to increase the capacity of the transmission lines.

4. In order to save current the following measures and devices should be considered :

a) the use of synchronous machines as power factor correctors to reduce the reactive load of overloaded transmission lines;

b) suitable distribution of the active and reactive load between the different power houses in order to reduce the losses in the interconnecting lines;

c) the reduction of the losses by discharge at the insulators of very-high voltage transmision lines by increasing the number of elements of the chains of insulators and by fitting guard rings at both ends of these chains so as to apportion the potential.

d) the reduction of the corona loss on very-high voltage lines by using larger-diameter cables and even hollow cables.

C. — Substations.

By substation we mean the complete plant necessary to transform or convert the current taken from a distribution network, including also coupling apparatus, control and signalling devices needed to feed the contact lines and locate failures. Whatever be their kind, substations are relatively costly installations; therefore the number of sub-stations needed to feed the contact lines is reduced to a minimum generally dictated by the permissible voltage drop in the contact lines, which ultimately results in power losses. Current savings will consequently be effected if the number of substations can be increased suitably. However, if such step is not to mean excessive expenditure, substation working costs must be reduced. To this end the following means may be mentioned :

a) Introduction of remote or automatic control in order to reduce staff ex-

penses. Thanks to the simplicity and working reliability of transformers and mutators, this method can be applied to both the fundamental electric traction systems : direct current and single-phase. Experiments carried out with more or less complete automatism have proved conclusive, and largely furthered the development of this method of control;

b) Installation of transformer plants to feed alternating current to the contact lines, such plants only consisting of a transformer installed in the open, together with the necessary circuit breakers. Transformer plant differs from the substation in that the installation is of the simplest kind and that the switchgear is operated by staff from a nearby station, when requested to do so by a power house or substation;

c) Use of mobile substations, mounted on wagons. Such substations found a first application on some mountain railways, with seasonal traffic.

The *Italian State Railways* introduced them on a larger scale for three-phase and D. C. traction, in order to assist a fixed substation which can no longer meet the needs of the System, particularly periodical or exceptional peak loads. By the use of mobile substations, reserve groups can be made better use of, and their number reduced to a minimum.

The substation equipment is decided first of all by the type of the primary current and the traction system, and secondly by the most suitable and economical methods of transformation or conversion, or these two functions together, and finally by the working conditions.

The universally used *transformer,* by its nature, by its very high efficiency, and by being static, can be considered as almost perfect.

Humanly speaking it cannot be improved so as to economise current seeing that any reduction in the losses in the copper and in the iron involving such an increase in the cost that it is not an improvement in the usual meaning of the word. The excitation current of the transformer is provided by the primary voltage and not by the power or load of the latter. It produces the no-load losses to which have to be added the losses under load, and lowers the power factor of the primary transmission system, by phase displacement. Such defects for a given total transformer power increase with the number of transformers; to reduce it, large units must therefore be selected. The choice is an easy one as the reliability of the transformers is now very great. The number of transformers required can also be reduced by increasing their overload capacity by adequate cooling. The efficiency of the transformer is 98 to 99 %.

The *converter group* consisting of a three-phase asynchronous or synchronous motor and a generator has an efficiency varying between 81 and 90 %, between half and full load. In view of the rate energy used on a railway, the average efficiency in service is lower than 81 % and is further reduced by the transformer losses.

The advantage of the synchronous motor-driven converter is that it can act simultaneously as a phase advancer and either improve the power factor of the primary transmission system or at least not reduce it. This advantage, however, does not make up for the low efficiency.

The *rotary converter,* which combines in one unit the motor and the generator of a converter set, increases the efficiency of conversion from 92 to 96 % at half and full load. Against this, as it is excited by the direct-current voltage, it cannot work independently as a phase advancer like the synchronous motor of the converter set.

The *mutator* with its almost constant efficiency of 98 % at 1 500 to 3 000 volts

without a transformer and of 96 % with one would be, through this alone, the most economical method of converting three-phase into direct current. It is also the most economical method through its other properties we have already examined; these are, from the technical point of view, the regulation of the voltage and protection against overload currents, and from the economic aspect its lower cost as compared with converters, its simplicity, and its reliability.

The mutator can be fed by a transformer with simple six-phase coupling or double three-phase coupling with a phase equaliser. The latter has the advantage over the former of reducing the specific current of the different anodes, by a better division and also by increasing in this way the overload capacity of the mutator, and of reducing the voltage drops in the arc and improving the efficiency of the plant.

No further improvement in the efficiency of the mutator can be looked for except possibly in reducing the auxiliary losses to the minimum. One of the methods employed in this connection is the proper ventilation of the buildings. This may be a serious matter in places where the temperature in substations has to be maintained at some degrees above the outside temperature to prevent moisture condensing on the metal parts of the equipment, and where in very cold weather it becomes necessary to increase the heating by electric radiators.

Up to the present one of the most interesting applications of the mutator is, according to the particulars given in the *Brown-Boveri Review,* in the Italian State Railways' substation at S. Viola-Bologna, feeding the Bologna-Florence « Direttissima ». This substation is the junction point of two completely independent three-phase 42-cycle transmission systems. It is equipped with three A.C.-D.C. 2 000 kw. at 3000 volts mutators, two being reversible and the third only working as A.C.-D.C. The characteristics of this installation are :

a) the voltage on the contact line can be regulated between 3 000 and 3 400 volts;

b) the mutators can be connected to either three-phase system at will;

c) the polarisation of the grid is controlled by a contactor with a brush revolving at the synchronising speed, polarisation being governed in this way by the frequency of the A.C. transmission system, and starting the arc at the anodes at the desired instant;

d) the current required to polarise the grids is supplied by a small converter group;

e) the two reversible mutators are fitted with automatic power regulators. The non-reversible A.C.-D.C. mutator is not regulated;

f) when working A.C.-D.C., the three mutators are protected against overloads by a quick-acting relay, controlled by the primary current which, if a short-circuit occurs makes all the grids negative and so blocks the current. When the two reversible mutators work D.C.-A.C., a short-circuit on the three-phase side also causes a short-circuit on the D.C. side, as there is no back e.m.f. in the transformers. In this case the mutators are protected by quick-acting circuit breakers.

g) the secondary phase voltages are adjusted to the A.C.-D.C. and D.C.-A.C. working by tappings on the transformer primary windings.

h) the S. Viola-Bologna substation is arranged to feed the contact line from one or the other or both the A.C. transmission systems. It can be used as well to couple up the two A.C. transmission systems through the mutators, which makes it possible to exchange power between the D. C. system and the two A.C. systems.

i) the power absorbed by one or supplied to the other A.C. system can be limited to definite values at will.

At the present time three-phase industrial-frequency current can only be converted into single or three-phase low-frequency current by rotary converters. The *alternating-alternating mutator,* although it has been tested and has given satisfactory results in practice, is still in the development stage. It appears likely, however, that it will fulfil in single-phase traction work the same functions as the A.C.-D.C. and D.C.-A.C. mutator fills in D.C. traction.

The principal difficulty to be overcome is caused by the deformation of the primary wave and the spreading of the pulsating load as single-phase over the phases of the three-phase system.

The three-phase single-phase converters which are called *frequency converters* are of two types : the rigid and the flexible.

The « rigid » type consists of a three-phase synchronous or asynchronous machine and a single-phase generator. Whilst the synchronous three-phase machine and the single-phase generator revolve in absolute synchronism with the frequency of the network to which they are connected, the asynchronous machine shows a certain slip depending on the load. According as the machine works as a motor or as a generator, this slip means a reduction or increase in speed relatively to the speed of synchronism.

The slip at normal load is only some 0.5 to 0.75 % ; every variation above or below means a proportional increase or reduction in the load. Now frequency variations in an industrial transmission system are as much as $\pm$ 1 %, and in an independent railway system $\pm$ 3 %. The asynchronous motor, therefore, in spite of the slip, does not lend itself at all to coupling together two independent transmission systems, the frequency of which is not constant. This is why we consider the asynchronous motor as also rigid. The rigid frequency converter is used to feed all or part of a railway through a single three-phase transmission system and also to couple one of the alternators of an independent power station to a traction system fed by other power stations of insufficient capacity. With a power factor of 0.8 its efficiency varies between 85 and 90 % from half to full load.

The *flexible frequency converter set* solves in a practical way the technical problem of exchanging energy between the industrial three-phase system and the single-phase traction system. The set itself includes a single-phase synchronous machine and its exciter, a three-phase asynchronous machine, a Scherbius machine with commutators regulating the three-phase asynchronous machine, and a frequency converter for the exciter of the Scherbius machine. The interlocking, regulating, measuring, and signalling gear is in proportion to the make up of the group, and is therefore not very simple.

Groups of this kind have been in service several years and work with great regularity and with the required reliability; they meet the following requirements :

1. Output in both directions of constant tractive power adjustable between zero and the maximum allowable, independently of frequency variations and of difference between the frequencies of the two transmission systems coupled together;

2. Transmission of the energy according to the frequency of one of the transmission systems and independently of the frequency variation of the other system.

3. Separate feeding of a section of the contact lines;

4. Output of reactive energy of the two main machines controllable at will as regards quantity and direction.

The efficiency of the flexible converter is rather lower than that of the rigid converter because of the number of machines; at a power factor of 0.8, it varies from 83 to 88 % from half to full load.

The complete installation of a flexible converter involves a considerable outlay, and for this reason cannot become general practice.

In order to reduce the cost of installing and working frequency converters and the amount of current used, *the production of single-phase current at the contact line voltage* can be considered.

Double transformation will be avoided, whereas the three-phase current *must* be transformed owing to its much higher voltage. This solution has been adopted in one of the most recent installations; the 15-kV. line, however, is not fed directly but through a feeder line several kilometres long, less exposed to short-circuits than the contact line, which acts as a damper.

The voltage selected for an earlier installation with direct feed to the contact line was that best suited to the windings of the two main single- and three-phase machines, namely 8 600 volts, and a step-up transformer (from 8 000 to 15 000 volts) was installed, and acted at the same time as a damper of the short-circuit currents. The second measure is to install as large units as possible, so as to reduce their number. Thanks to the high voltage of the single-phase current, the substations could be spaced very far apart, which increases their load; the load on the converters can be increased still further if intermediate transformers supplied by feeders at higher voltage than the contact line, such as 30 kV., are resorted to. The converter then works on a transformer with 3 windings, one of the two secondary windings supplying the voltage of the contact line and the other that of the feeder. This feeder takes the place of a contact line feeder and can be single-pole, the rail being used as the return, the better because the return current being at the double voltage of the feeder is inversely smaller. Then too, when the ratio is as 1 to 2, auto-transformers can be used with advantage as the losses are less than in an ordinary transformer.

The peak loads, i.e. infrequent loads, of short duration, by exceeding appreciably the average load of the substations and resulting from the traffic being particularly heavy at certain moments of the day, have many serious drawbacks. They increase the costs of installation, the voltage drops, and energy losses considerably.

The *load factor* of a substation, obtained by dividing the peak load recorded by the arithmetical mean load over 24 hours, varies widely. It is more or less a function of the energy absorbed although, of course, it depends too on other factors inherent in railway working, such as the gradient section and the weight, speed, and frequency of the trains. However much influence these factors may have, the graphical representation of the power factor in terms of the energy absorbed follows a hyperbola.

Taking the weekly consumption so as to cover the working days, Sundays and holidays, this load factor is seen to be 12 when the consumption is below 50 000 kWh.; it falls rapidly to about 4 as the consumption increases to 500 000 kWh., and barely falls below 2 for a consumption exceeding 1 500 000 kWh. The weekly output of 50 000 kWh. is that of a small substation feeding a 20 to 30 km. (12.4 to 18.6 miles) section of line. The load factor of a large railway taken as a whole therefore improves with the number and size of the substations. This shows that small companies have much interest in reducing the power factor according to the conditions under which they are supplied with power. The interest in the case of large

railways lies mainly in the savings to be effected in the capital expenditure and the working costs of the substations.

The load factor can be very much reduced by distributing the trains uniformly over the twenty-four hours and taking care that several trains are not allowed to work up the heavy gradients of the railway at the same time.

With regard to the question of the *train timetables* being based on the energy available or on the load of the system, the Member Administrations who sent in information replied in the negative; one of them, however, has investigated the question for a suburban railway with a load factor of 12 and 13. Consequently any restriction on running the trains are incompatible with the needs of a large railway system, whereas it is an economy in the case of railways which can observe them more or less without great inconvenience.

Once the train workings are drawn-up, the load of the railway is known with its periods of light traffic and its peak loads corresponding to the normal rate of consumption of power.

This rate is altered — always towards overloading — when a more or less considerable number of trains have to be run in special circumstances. Thus, the substation equipment has to meet the regular peak loads and in addition the exceptional loads. As a first step to meet this requirement the substation equipment has to have a high *overload capacity*. This capacity is about 50 % of that of the equipment always in use, for 1 to 2 hours, and 200 to 300 % for 5 minutes. Owing to the load factor of the substations, which varies between 4 and 12, the peak loads still considerably exceed the overload capacity of the equipment. The number of units therefore is decided by the exceptional loads on the substations. These peak loads succeed one another with a regular rhythm or under previously determinable circumstances. The number of units in service consequently can be increased or reduced according to requirements, thereby saving current. The practice of *adapting the number of units in use to the load* is more general in D.C. traction work than in A.C., either because the conversion losses and the load variations are larger or because the units are smaller and lend themselves better to this practice, or finally because the installation allows certain units to be switched into and out of service very simply. The automatic control is obtained by means of amperemetric and thermic overload relays.

The number of traction groups is adjusted by hand to suit the substation load 2 or 3 times a day on the railways on which this practice is followed.

The recovery of energy regenerated during braking and not absorbed by the contact line only involves special substation equipment when A.C. is being converted into D.C. No additional equipment is required in A.C. work where the current is only transformed from one voltage to another, and where single-phase current is transformed into three-phase by frequency converters. In the A.C.-D.C. converters special arrangements have to be made when regenerating, owing to the compound excitation. These arrangements bring us back to fitting a device for shunting the compound windings by a contactor operating by means of relays the moment there is any back current. The poles of the machines have one or two anti-compounding windings to compensate the action of the shunted compound windings. In substations with A.C.-D.C. mutators, some of the latter should be reversible to allow the regenerated current to pass to the three-phase distribution system.

Summary.

1. *Methods and equipment used with all traction systems :*

a) Introduction of remote control or

of full or partial automaticity to reduce power station operating costs and accessorily to make it easier to increase the number of points at which the line is fed;

b) Use of mobile power stations on some railways carrying traffic of a seasonal character, either to assist the existing substations, or to increase the number of points at which the line is fed during the heavy traffic period;

c) Equipment of substations with machines and equipment having a high momentary overload capacity, in order to be able to reduce either their continuous power or the number of units required to meet the peak loads, and thereby reduce the no-load losses;

d) Adjustment of the substation power to the working load by starting up or stopping traction groups or even complete substations to reduce the no-load losses;

e) Reduction of the load factor on lines on which the train working can be adapted more or less to suit the load on the substation.

2. *Methods and equipment specially adapted for use in conjunction with D.C. traction.*

a) Use of mutators in order to reduce the capital costs of substations and the losses in transforming A.C. into D.C.;

b) Use of double three-phase coupling with phase equaliser for the transformers feeding the mutators in order to increase the overload capacity, reduce the voltage drop, and improve the efficiency of the equipment.

c) Installation of reversible mutators for exchanging energy between the contact lines and the three-phase system or systems either for regenerating the energy recovered during electric braking, not absorbed by the contact lines, or for using the superfluous energy of the power stations operated by the Railways.

3. *Methods and equipment specially used in connection with alternating traction current.*

a) Installation of intermediate transformer stations to increase the number of feed points at the least cost.

b) Use of the flexible frequency converter to enable a railway owning its own power station to take additional energy at constant power from an industrial system so as not to vary the load on this system greatly, and to be able to exchange energy;

c) Increase of the voltage in feeders using the rail as the return conductor, and, conjointly therewith, use of autotransformers at the intermediate feed points in order to use the converter groups more efficiently.

D. — Contact lines.

1. *Third rail.*

The extension of low-tension D.C. traction on main lines necessitates the transmission of very heavy current to high capacity motor coaches. The third rail becomes the only type of contact line from which the current could be picked up and through which it could be transmitted over satisfactory distances without using feeders. So as not to wander from the subject, we have made no attempt to enquire how far the dangers and disadvantages of all kinds of the third rail favours high-voltage traction and the overhead line. It will be enough to state that the drawbacks of the third rail were sufficient in some cases to give preference to the double-pole contact line of the three-phase system, and then to the single-phase system in order not to throw away the advantages of the single-pole line and be able to increase the voltage still further, this being at a period when the single-phase traction motors were still very far from perfect.

The third rail, however, can be used advantageously in certain cases such as city and suburban railways, chiefly carrying passengers. The conductor rails weigh 39, 50 and 76 kgr./m. (78.6, 100.8 and 153.2 lb. p. yd.), a special low carbon manganese steel being used to increase the conductivity. The resistance of this steel is only eight times that of copper instead of about 12 times in the case of ordinary rails. The composition of the conductor rails on the Paris-Orléans is as follows :

Carbon	0.09 %
Manganese	0.42 %
Sulphur	0.05 %
Silicon	0.09 %
Phosphorus	0.03 %

Two Companies owning together 214 km. (133 miles) of track equipped, with third rail have improved the conductivity by thermit-welding the rails instead of using copper bonds. The length of rail welded together is about 300 m. (984').

2. *Overhead trolley line.*

The advantages of A.C. traction over D.C. rest on the fact that the voltage can be raised or lowered at will between any practical limits. In three-phase traction work, the usual voltage adopted is 3 000 to 3 700 at the trolley wire, and in exceptional cases 6 000. The voltage is limited by the difficulty of insulating the two aerial phases to the point at which the current is taken by the locomotive.

The choice of voltages of 10 to 15 kV. in the case of single-phase was determined by considerations of safe working. The more extensively any system is in use, the more difficult it is to change any of its fundamental characteristics. Consequently a change in the standard voltage or frequency of the alternating traction current cannot be considered as a method of saving current.

Two voltages, 1 500 and 3 000, confront us in D.C. traction work. As any suitable voltage for traction work can be produced with the mutator, under the required conditions of reliability in traffic working, the commutator of the D.C. motors are the limiting factor. No simple and economical method of lowering the voltage as in the case of transforming alternating current is known at present.

The manufacturers have built successfully 3 000-volt traction motors, but the cost is still appreciably higher than that of 1 500-volt D.C. equipment. At the present time, however, it is almost generally agreed that 3 000 volts is the better tension.

Some railways are still using the 3rd rail for 1 500 volts, which appears to be the practical limit. The overhead line is the only one in the field when transmitting higher voltages. Copper, on account of its electrical and mechanical properties, is the only possible metal for the overhead line. The cross section is governed by mechanical considerations. Too rigid a wire would take the characteristics of a bar and be difficult to unroll and fasten; it also would deprive the line of the flexibility required, if the current is to be picked up properly at high speed. The usual section used on main lines is about 100 to 110 mm^2 (0.155 to 1.705 sq. in.). The contact this wire makes with the locomotive pantographs is large enough to carry the largest amperage required with 15 kV. When dealing with the much heavier currents at 3 000 volts, the contact surface and the conductivity are increased by doubling the overhead wire.

The resistivity of the copper of the line and of the feeder has to be added to that of the return circuit through the running rails and the earth. This latter resistivity reduces the degree the copper in the line is used in proportion to the increase in its cross section, for the simple reason that this constant is proportionally the greater the smaller the resistivity of the line. Whilst this pro-

portion is true for a D.C. system, it is aggravated in the case of A.C. by the self-induction of the line, the reactance. This component of the impedance depends on the arrangement of the conductors in a circuit, relatively to one another, and therefore does not diminish in the same proportion as the other component, the ohmic resistance.

Consequently the degree of use of the copper in an A.C. line diminishes more quickly with the increase in sectional area than in a D.C. line; in other words, the section of copper of an A.C. line cannot be increased economically like that of a D.C. line.

The permissible voltage drop, the energy losses, the cost of copper, power and substations are some of the variables governing the most economic section of copper.

On 3 650 km. (2 268 miles) of 1 500 and 3 000-volt D.C. track the sections of copper or their equivalents in the line and feeders together but ignoring the running rails are as follows :

1 100 mm²	(1.705 sq. in.)	on about 5 % of the length,
642 to 660 mm²	(0.995 to 1.02 sq. in.)	on about 49 % of the length,
435 to 490 mm²	(0.679 to 0.759 sq. in.)	on about 26 % of the length,
100 to 330 mm²	(0.155 to 0.511 sq. in.)	on about 20 % of the length.

On the 2 626 km. (1 637 miles) of single-phase 11 000 and 15 000-volt electrified track covered by our report, the sections are as follows :

100 to 135 mm²	(0.155 to 0.209 sq. in.)	on about 23 % of the length,
150 to 220 mm²	(0.233 to 0.341 sq. in.)	on about 77 % of the length.

The comparison between these sections brings out a characteristic difference between the two systems under consideration : that in one the absence of inductive effects with D.C. allows large sections of copper to be used, whereas in the other these effects and the much smaller section of copper are balanced by the smaller current at the much higher voltage.

The same precautions are not required with the two systems — D.C. and A.C. — when the *running rails* are used as conductors. This is due chiefly to the stray earth currents the electrolytic action of which can destroy the metal mains laid in the ground, whereas in the case of A.C. no such action need be feared. This makes it essential in D.C. work to provide conductors for the return current so as to prevent its dispersion in the ground. This can also be necessary, though less so in the case of A.C. work, for two other reasons : firstly owing to the electro-magnetic induction effects in the overhead and underground lines carrying little current and then through the thermal effects of the stray currents concentrated on underground metal-clad cables. The currents in the single-phase line set up electro-magnetic effects which can induce voltages in the overhead line and in the core of cables carrying low currents, and an induced current in the metal sheath of the cables. These induction effects fall off proportionally as the current in the running rails increases. A heating effect due to the stray currents has been observed in two particular cases :

1. On lines with underground cables laid in a bed of sand along and very close to the track and where the muddy rail joints had conducted to some extent the current from passing locomotives, from the running rail to the lead sheathing of the cables;

2. In a substation in which the earthing was inadequate to deal with the stray currents in spite of the running roads being well connected to the substation.

In the first case the danger is greatest in wet tunnels. To avoid it all that is needed is to make sure there is no break in the continuity of the rails by proper bonds at the joints, to insure the current is dispersed to earth over a long enough distance. In the second case a good earth has to be made, covering a large area. In A.C. installations, the earth can be used to take the return current without serious drawbacks, thereby increasing the conductivity of the return circuit. This advantage is additional to that of the lower current at high voltages.

When the values of the ohmic resistance of the rails on double and on single-track are compared, the earth is found to increase the conductivity of a single track with rail bonds by 40 %. This increase can be taken as 100 % in the case of lines whereon electric rail bonds are used.

Electric bonding is essential to canalise the return current in D.C. working, and consequently the bonding should be improved in every possible way in order to save current. With A.C. traction, however, electric bonding solely used for this particular purpose is either useless or at least costly.

Copper bonds welded to the foot or head of the rail are used in general, instead of being bolted or wedged, *to provide the electric fishing.*

Equipotential bonds between parallel tracks are in general use, but the spacing varies, being from 100 m. (328′) up to 3 km. (1.86 miles). The object of these bonds is to distribute the return current over the various parallel tracks and thereby overcome any break in continuity if the electric bonding broke down. The much less importance now attached to these fittings in new works is shown by the much greater distance apart they are fitted.

None of the D.C. railways covered by our report uses a *return conductor* parallel to the track, to increase its conductivity. A negative feeder of this kind has only been provided to connect certain substations to the railway and between the entrance and outlet of certain spiral tunnels, outside the tunnels. In view of the large sectional area of copper in the D.C. line, the track can deal with the heaviest currents, which must be maintained in the running rails as far as possible.

For this reason *earth plates* are not and cannot be used in D.C. work to facilitate the return through the earth. The earthing wires of the contact line supports, by connection of the support to the running rails, are even insulated. In some earlier single-phase installations, earth plates were used and still exist in the mountains where the track is mostly carried on rock. They have been given up in recent work in view of the advantage of holding part of the current in the rails. The wires earthing the supports of single-phase lines, on the contrary, are not insulated; bare copper wire is used and is earthed between the support and the rail without protection. In view of their large number, these wires provide an efficient and adequate earth.

The *power losses* in the contact lines are about 10 to 12 % with D.C., and 4 % with single-phase current, and are inherent in the system. When two systems are contrasted in this respect, the difference is found to be made good by the other disadvantages and advantages each possesses.

The *power factor* of single-phase energy in the line depends on the work done by the locomotives in service; it is low when the locomotives are running light, and improves as their load increases, and therefore with the load of the contact line and the substations, where it rises to 0.87, a satisfactory value. The only way in which this power factor could be improved still further is by special steps being taken on the locomotives. The relatively small losses in the line would be reduced very slightly and the result

would be negative for many obvious reasons, if not because of it being practically impossible.

Summary.

Methods and arrangements to use in D.C. work :

a) Improving the conductivity of the 3rd rail by thermit-welding together several rails and by using copper bonds secured by autogenous welding;

b) Fixing the electric bonds to the running rails by autogenous welding, in order to ensure perfect contact;

c) Using 3 000-volt current when financial considerations will admit the use of the more expensive 3 000-volt motors instead of the cheaper 1 500-volt motors.

2. *Methods and equipment to be used in single-phase traction work :*

a) Pressures of 11 kV. are suitable for small railways, and 15 kV. for large-ones. The voltage can be increased to 20 kV. when it is not tied by standards and when dealing with long-distance lines and not a circumscribed railway system.

b) Electrically bonding the running rails when the voltage is 11 kV. or over to the extent it is useful and opportune for reducing the induced voltage in the railway company's low-current cables.

E. — Rolling stock.

1. *Locomotives.*

The replies of the Railway Administrations to the first question asked them — the steps they have taken to reduce the dead weight of the locomotives — were that they had not thought it advisable to do so, either so as not to reduce the adhesive weight or because it was of no value or was costly, or lastly in some cases, because they had no locomotives.

A negative answer was to be expected in the case of D.C. locomotives, because the main electrical part, the motor, is the lightest per unit of power of the three classic types. In addition, this motor was introduced into electric traction work long ago and was improved as far as possible at a comparatively early date.

The weight of the locomotive per unit of power depends on the speed and the tractive effort developed as well as on what is to be meant by « the power of the locomotive ». We found that the power of D.C. locomotives at the hourly rating is proportionally higher relatively to the continuous rating than that of single-phase locomotives. This is also the case as regards the tractive effort at starting and consequently as regards the adhesive weight. Any comparison of locomotive weights ignoring these factors is inaccurate. So as not to fall into this error, we shall compare only the weights of locomotives of the same class and type. The specific weight of old and new D.C. locomotives varies but little in fact, which proves that the weight of such locomotives is governed by the required adhesion and by the arrangement and devices necessary to get good running qualities.

When the weights of old and new single-phase locomotives are compared, the position is different. Whereas about 1912 the specific weight was some 100 to 140 kgr. (220 to 308 lb.) per H.P. at the hourly rating for 500 to 100-H.P. locomotives and in 1920, 60 to 85 kgr. (132 to 187 lb.) for 1 000 to 2 000 H.P. locomotives, to-day it varies between 40 and 26 kgr. (88 and 57 lb.) per H.P. for 2 000 to 6 000-H.P. high-speed locomotives, and from 55 to 35 kgr. (121 to 77 lb.) for goods locomotives. The locomotive stock of the *Swiss Federal Railways* contains the following two typical proofs of the attention paid during the period, to reducing the specific weight and increas-

ing the specific power of single-phase locomotives :

1. The *Be* 4/6 class locomotives with combined gear and rod drive, all designed for the same maximum speed of 75 km. (46.6 miles) an hour include 1 760-h.p. (hourly rating) locomotives delivered in 1929 and weighing 106.5 tons corresponding to a specific weight of 60 kgr. (132.3 lb.) per h.p., whereas those supplied in 1922, of 2 040 h.p., weigh 109.6 tons, or 54 kgr. (119 lb.) per h.p., a reduction of 10 %.

2. The individual axle-driven A*e* 4/7 locomotives designed for a maximum speed of 100 km. (62 miles) an hour, delivered in 1927, weighed 118.2 tons and their horse-power was 2 800 (hourly rating), equal to 42.2 kgr. (92.8 lb.) per h.p., whereas those of 3 300 h.p. supplied later on weighed 120 tons or 36.4 kgr. (80.2 lb.) per h.p., i.e. a 14 % reduction.

This shows that the earliest single-phase locomotives were too heavy. Today their specific weight has been reduced to that of the D.C. locomotives, which explains why the railways have not sought to reduce the weight of recent locomotives still further.

The specific weight of the powerful locomotives being less than that of the less powerful ones, the tare weight at equal power is also smaller when working single than when double-headed.

It is therefore very important that the power of the locomotives should be adjusted with care to suit the railway traffic requirements. The opinion of the competent circles is that it is a great advantage for locomotives having to work a regular service to have an ample reserve of power. This is, however, a question of policy which arises each time the locomotive stock has to be increased or modernised and for which no rule can be laid down. Consequently, we need not include it in the measures to be adopted in the sense of the question we have to investigate.

When the first high-power electric locomotives were designed it was thought that individual axle drives and nose-suspended motors should be abandoned, and the whole power concentrated into one or at most two motors. The intention was to reduce the working weight of the motors, raise the centre of gravity, and by means of rod drive, lessen slipping. The axle drive of these locomotives is therefore collective, whether it is purely a rod drive or a rod and gear drive. Mechanical coupling of the axles involves strengthening the frame to avoid it being twisted and to prevent variations in the distance between the crank pin centres. Besides the problem of the individual axle drive for high-speeds has been solved in a satisfactory way by the use of the flexible link or spring drive. This strengthening cancels any weight saving accruing from the use of large motors. Then too, the motors or group of motors can be coupled together electrically to prevent any axle racing or slipping. This electric coupling does not appear absolutely essential as ammeters indicating to the driver any tendency to slip are found sufficient. All the Administrations, therefore, now agree that the advantages of the large traction motor and rod drive are not sufficient to retain them for electric traction.

The weight of traction motors has been reduced mainly by increasing their speed, and in addition in the case of single-phase motors, by using electric welding in manufacturing them.

The *speed* of traction motors is limited by the permissible circumferential speeds of the armature and commutator, and lies between 500 and 1 000 r.p.m.. On the newest high-power D.C. and single-phase locomotives the characteristics of the motors are much alike. The speed at the hourly rating is 700 r.p.m., and the gear ratio, according to the maximum speed of the locomotive, is 1 : 2.57 to 1 : 3.47.

The highest gear ratio reported is 1 : 576 in the case of 4 500-H.P. single-phase locomotives designed for a maximum speed of 75 km. (46.6 miles) an hour; it confirms the use of high-speed motors to reduce the weight of high-speed locomotives and of those having to develop a high tractive effort.

By reducing the sudden current fluctuations at starting, the power can be increased appreciably and held nearer the maximum power. The risk of slipping can be reduced or the proportion of adhesive weight used can be increased and also the acceleration. As D.C. locomotives can only be controlled by contactors the advantages of a fine regulation are not worth the complication entailed. Owing to the properties of alternating current, fine regulation is more easily provided on single-phase locomotives. However, the three Companies covered by this part of our report have not pressed it below the limit imposed by the overload capacity of the motors. The current surges, when passing from one control position to the next, are about 12 %.

In order to increase the *adhesive weight* of the locomotive when there is difficulty in starting, one railway uses compressed air operated gear which transfers part of the weight on the carrying wheels, the load on each pair of driving wheels being thus increased from 20 to 21.5 tons. On the locomotives in question this gear was used to take advantage of the increase in weight due to the regenerating equipment; this increase had involved the use of an additional carrying axle in order to keep within the maximum axle loads allowed at high speeds. Such gear can also be used to reduce the weight of high-speed locomotives which need guiding wheels to get the riding required.

Streamlining high-speed locomotives would only be effective if the trains were streamlined too. In view of the international character of many express trains, and the varying make up of the trains, no Railway has applied it to its locomotives.

2. *Electric motor coaches.*

The growing need for increasing the speed and frequency of trains, and for making the working more adaptable has given a fresh impulse to the use of electric motor coaches.

These coaches can be classified into three groups :

(1) the motor coaches doing the work of a small-power locomotive; (2) the individual light motor coach; and (3) the multiple-unit trains.

The use of these different types of electric motor coaches is a question much like that of adapting the power of the locomotives to the operating requirements, i.e. is outside the scope of our report.

Motor coaches of the 1st class can be compared with locomotives, as their power and weight are determined by the loads to be hauled. The only difference between these coaches and ordinary locomotives of low power is the arrangement of the body; they have no particular feature of interest so far as this report is concerned.

We can deal with the 2nd and 3rd groups together, as a multiple-unit set can be considered as an individual unit. They represent the new fashion in rolling stock, the chief features being the type of construction, the outside appearance, and the running speed. Except in certain particular instances, such as when electric motor coaches have to work in multiple units, or when interchangeability is the chief factor, attempts are being made everywhere to lighten this stock.

The steps taken in this respect are : Use of high-tensile steels in the underframes and light alloys in the bodies; welded construction; individual axle drive and use of high-speed motors running

at about 1 500 r.p.m. The running resistance is a function of the weight of the motor coach and of the square of the speed. Owing to the tendency to reduce the weight and increase the speed, the air resistance is becoming a factor of increasing importance for vehicles running by themselves. As this resistance acts chiefly on the head and tail ends of the train, the coach or rake can be streamlined more or less fully and, as in the case of the oil-engined railcars the floor can be lowered to bring down the height and thereby reduce the head-on surface. The depressed floor, however, means that the standard couplings cannot be used. Ordinary stock cannot be coupled up when it is necessary to strengthen the trains and the operating department loses the means of adapting the trains to the traffic of the moment. This partly explains why the single electric motor coach is less used than the internal-combustion-engined railcar still of limited power.

3. *Mutator-fitted locomotives.*

None of the railways dealt with possess a mutator-equipped locomotive, even an experimental one. The problem of feeding the line with 50-cycle industrial current to avoid transforming it in the substations might perhaps be solved by mounting the mutator on the locomotive. At first sight, in view of the present high standard of the single-phase motor, there would be no advantage in single-phase low frequency traction work to replace it by a D.C. motor.

4. *Ball or roller bearings.*

As regards current consumption. ball or roller bearings have much the same ideal coefficient of friction at rest as at any speed. Compared with the plain bearing, the starting resistance is much lower and also the running friction. The higher starting resistance of the plain bearing means a high tractive effort of short duration with a corresponding quantity of energy, so that the ball bearing makes the start easier and the acceleration can be higher. The running resistance of the bearings means a continuous loss of energy which can be reduced according to the conditions from 1/2 to 1/10. Ball bearings therefore can reduce appreciably the tractive effort, and the work done in moving the trains when they are fitted throughout. In spite of their other advantages, however, they have not come into general use on rolling stock. All Administrations have adopted them at least as a trial on the armature bearings of the traction motors, i.e. on bearings of medium size not subjected to shocks from the track. Ball and roller bearings are in use as journal bearings but chiefly experimentally, owing to the danger of balls or rollers breaking.

5. *Train heating.*

Electric train heating consumes 5 to 15 % of the total energy used. The different proportions between the energy for traction and for heating are due primarily to climatic conditions.

Taken over the heating period, the power for electrically heating the trains reaches and even exceeds 30 % of the average locomotive power. The result is that as much or even more power is required in winter than in summer, though the traffic is lighter. The low water level in winter, the losses in converting the heat into electric energy, the existence of steam heating equipment on the trains are some of the chief factors favouring coal-fired boilers for train heating.

We should go outside the limits of this report were we to examine this question in detail. All that need be said is that the advantages of heating the trains electrically are such that it is used by all the Railways having to heat their trains, who replied to the questionnaire. If electric heating is not the only me-

thod used, the exceptions may be said to be due to the exchange of rolling stock with steam-operated railways.

We cannot, therefore, report any known example of the coal fired boiler for train heating as a means of saving current, in the meaning of the question we had to investigate.

The ordinary method in general use is to use electric radiators inside the bodies. Following steam heating practice, the electric radiators can be switched on or off by the passengers at will. Each switch has three positions : off, half, and full heating power.

The train staff generally controls the heating when radiators are used. In the case of A.C. a variable heating voltage can be taken quite easily from the locomotive transformer, and thereby adapt the heating power more closely to suit the outside conditions. The *Swiss Federal Railways* use an intermediate pressure of 800 volts, which relatively to the normal 1 000 volts, reduces the heating by 36 %, but is satisfactory for heating the trains in mid-season.

Automatic control in any case prevents the stock being overheated, which occurs frequently and is almost unavoidable with manual control. Supervision by the train staff is made easier in preventing waste of current, by heating with the doors and windows open. On the Milan-Varese-Porto-Ceresio line, 40 motor coaches and 60 carriages have been equipped with thermostatically controlled radiators. The railway estimates a 45 % current saving.

Several Railways are testing on a few ordinary coaches and motor coaches an electric heating system by hot air under pressure in conjunction with an automatically controlled central heater under the floor of each vehicle. This system heats more quickly than when radiators are used; the preliminary heating period can be reduced and a current saving effected.

6. *Regenerative braking.*

Braking by regeneration is not used to stop a train but to reduce its speed on steep gradients. It involves additional equipment on the locomotive and therefore increased weight in both direct and single-phase current work.

This increase varies within much the same limits for the two traction systems, namely 3 500 to 8 000 kgr. (3.5 to 8 tons) in the case of engines of over 100 tons, i.e. 3 to 4 % of the weight of the locomotive. The energy involved in carrying this additional weight has to be deducted from the energy regenerated. If the cost of installation be taken into account as well, regenerative braking is only economical on lines with long steep gradients, as it increases the safety and reduces considerably the wear of tyres and brake shoes.

In D.C. and three-phase traction, regenerative braking begins to be used when the gradients exceed about 1 in 100. The whole of the braking energy is recovered usually; only part is regenerated when the permissible load on the motors is exceeded.

The proportion between the energy regenerated and the braking energy is therefore very high. On the *Algerian Railways* the proportion is 90 %.

In single-phase work, regeneration is possible either by induction windings or by using frequency converters to excite the traction motors. The increase in weight due to these two additional equipments is about the same.

The induction winding method is simple, but it considerably reduces the power factor, which then becomes 0.5. The braking current required becomes too high to hold the whole train.

The Swiss Federal Railways and the Rhætian Railways selected simplicity instead of the other advantage. Both these Administrations employ regenerative braking on 1 in 38 to 1 in 22 gradients to hold only the locomotive, i.e.

30 to 35 % of the whole train weight. With such proportion between mechanical braking and electrical braking, there should no longer be any apprehension about what would happen if regenerative braking came to fail suddenly owing to an untimely break on the locomotive or in a substation. In any case, it is necessary that the supply network be able to absorb at any time the power recovered. Thus the *Loetschberg Railway* had to have recourse to rheostatic braking because its line is fed by means of single-phase alternators, and the above condition is consequently not fulfilled. On the other hand, on the *Algerian Railways,* the amount of energy recovered exceeds the output of the power house, and is damped out in a liquid resistance which cuts in automatically.

7. *Measuring the current.*

The measurement of the current used on the locomotives, with a view to interesting the men, can be a suitable method of reducing consumption in certain cases. Although this question was not in the questionnaire, we must refer to it as it has been mentioned by a railway using it.

Its value naturally depends on the wastage of current which may still result from the carelessness of the drivers.

On steam locomotives, the production of steam to meet the demand at all times depends on the skill with which the grate is fired, and the fire regulated.

The efficiency of the locomotive is directly proportional to the steam pressure so it has to be kept at its highest value. As the fire cannot respond instantaneously to the available means of regulation, these are completed by the safety valve which allows any excess steam to escape. The coal consumption therefore depends largely on the care of the enginemen. Most of the railways consequently have always awarded coal premiums to interest the enginemen in saving it. Coal consumption can be controlled easily as the mileage the engines run is governed by having to take coal and because of the marked difference between the passenger and the goods engines.

In electric traction work, the driver has nothing to do with producing the energy for the locomotive; he takes it from the contact line by simply varying the motor control. On single-phase locomotives the starting and the speed regulation are effected by varying the voltage at the motor terminals, the voltages needed being supplied by the transformer as desired.

Only D.C. locomotives require starting resistances, which waste large or small quantities of energy, according to the starting conditions. The running speed, on the other hand, can be regulated by coupling the motors in series, series-parallel and in parallel; and in addition by the graduated shunting of the motor field coils.

Here again we must leave aside current savings which might be obtained by using to a larger extent the potential energy of the train, i.e. by reducing the energy losses by braking. The working speed of the trains is more and more dictated by the need of meeting the demands on the railways, to which certain economic considerations have to give way.

The drivers of electric locomotives can only affect the power consumption by seeing the brakes are released in time and, in D.C. work by seeing the starting resistances are used suitably.

Besides, the flexibility of electric locomotives has incited the railways to make them more and more universal so that they can be used indifferently on either passenger or goods trains, and so lengthen the mileage run and the work done each day.

This method of operation implies the pooling of locomotives. The check on the energy consumption which as we have just seen, has no longer the same

effect as that on coal consumption becomes illusory and even impossible in a large railway undertaking. It can be said, therefore, that the control of power consumption is only practicable on lines on which the make-up of the trains, intended for a regular and steady flow of traffic is always alike.

Summary.

1. *Locomotives.*

The weight of the locomotives of the three traction systems only depends on adhesion and running conditions. On high-speed locomotives having the relatively smaller tractive effort, the limit of adhesion appears to be obtained with direct or single-phase current motors, running at 700 r.p.m. (hourly rating). The weight of single-phase locomotives is reduced, in addition, by using welded mild-steel frames.

Ball bearings are still used to a restricted extent on traction motors, and hardly at all as axle bearings.

The large motor, even more efficient, used in the place of the small motors required for individual axle drive, does not reduce the energy consumption owing to the greater weight resulting from the strengthened frames.

2. *Electric motor coaches.*

High-tensile steels, light alloys and welding are all used with advantage to reduce the weight of the motor coaches. A further reduction is obtained by the use of high-speed motors, running at about 1 500 r.p.m. at the hourly rating, which motors, owing to their relative lightness, can still be nose suspended. Streamlining appreciably reduces the air resistance of separate vehicles. The rolling resistance is reduced as a rule by using ball or roller bearings for the motor armatures and also for the axle-boxes.

3. *Train heating.*

a) With A.C. traction the heat can be adjusted to suit the atmospheric temperatures by secondary tappings from the locomotive transformer.

b) Self-regulation of the heat prevents overheating and facilitates the supervision the train staff should carry out to prevent wastage of current.

c) Electric heating by forced hot air draught will allow of the preheating period being reduced.

4. *Regenerative braking.*

Against the drawback of running at speeds very near to synchronism, the three-phase motor has the advantage of changing its function as motor into that of alternator as soon as its speed exceeds that of synchronism, and so regenerating the work it opposes to the motion of the train.

In D.C. or single-phase traction, rheostatic or regenerative braking means additional equipment and an increase in the weight of the locomotive. This method of braking, therefore, is only advantageous on hilly lines, on which its main advantage is a considerable saving of locomotive tyres and brake blocks. Regenerative braking is therefore used preferably wherever the transmission lines can absorb at any time the energy regenerated. The braking is either wholly or partly regenerative according to the degree of safety required should it, for some cause or another, suddenly stop functioning.

APPENDICES.

Direct-cur

Questions.	Direct-current traction.	*P.O.-Midi Rys.* 2
	A. **General.**	
1	*Length of electrified lines, in kilometres :*	
	a) *single track*	972
	b) *double track*	1 457
	c) *multiple track*	89
	d) *together*	2 518
	e) *in course of electrification*	347 (double trac
	f) *projected*	473 (double trac
2	*Nominal current voltage*	1 500 V. on 2 408 km. 850 V. on 63 km. (third rail).
3	*Yearly power consumption*	450 × 10^6 kWh.
4	*Place where purchased energy (if any) is received.* .	At the incoming side of the substi (part of the energy is produ hydro-electric power houses bel to the Railway).
5	*Load factor :*	
	a) *at power house or place where power is received.*	Very variable, depends on the available.
	b) *at substations transmitting to the contact line :*	
	1. *up to 50 000 kWh. per week*	...
	2. *from 50 000 kWh. to 200 000 kWh. per week.*	...
	3. *from 200 000 kWh. to 500 000 kWh. per week.*	...
	4. *more than 500 000 kWh. per week.*	...
6	*Average power factor :*	
	a) *at power house*	0.95 to 0.98
	b) *at substations*	About 1.
7	*Drawing up train timetables taking into account surplus power and load conditions of the electric system.*	No.
	B. **Transmission lines.**	
1	*Distribution system :*	
	a) *independent*	Two 90 and 60-kV networks mair tributing the energy to the tions.
	b) *joint.*	Two interconnecting networks and 150 kV.
	c) *kind of current*	Three phase, 50-cycle.
2	*Approximate length of transmission lines, in kilometres*	At 220 kV. — 422 km. At 150 kV. — 805 km. At 90 kV. — 1 220 km. At 60 kV. — 1 613 km. Projected : at 150 kV. — 100 km. at 60 kV. — 340 km. at 90 kV. — 154 km.

stems.

French State Rys. 3	*Paris-Lyon-Méditerranée (P.L.M.) Rys.* 4	*Ch. de fer économiques du Nord (France).* 5
3.4	...	49
112.4	134.6	...
...	...	...
115.8	134.6	49
495 (single track).	...	...
...	...	...
)0 V. on 495 km.)0 V. on 115.8 km.	1 500 V.	1 500 V.
58 × 10^6 kWh.	21 × 10^6 kWh. (Chambéry-Modane section).	1.1 × 10^6 kWh.
the incoming side of the substa-ions.	In a main station.	At the substations.
relatively to the maximum load or a period of 5 minutes.	4.39 at the main station relatively to the maximum load for a period of 5 minutes.	...
4.2 to 5.6	4 to 8	7
2.9 to 4.1	...	...
...	...	...
...	...	...
...	1 on the average.	0.8
...	...	...
, impossible in an exclusively sub-ırban passenger service.	No.	No.
lependent at present.	At 42 kV. from the main station to the substations.	None.
ked in the case of the Paris-Le Mans line now being electrified. 3-phase 50-cycle.	From the power house to the main station. 3-phase, 50-cycle.	At two substations. 3-phase, 50-cycle.
At 15 750 V. — 248 km.	At 42 kV. — 117.5 km.	...

Questions.	Direct-current traction. 1	P.O.-Midi Rys. 2
3	*For the last completed year of operation, max. load and energy consumption :* a) *max. power for traction purposes*	90-kV. system — 45 000 kW. 60-kV. system — 45 000 kW.
	b) *max. power for other purposes*	90-kV. system — 25 000 kW. 60-kV. system — 20 000 kW.
	c) *energy transmission for traction purposes.* . . .	90-kV. system — 205 × 10^6 60-kV. system — 185 × 10^6
	d) *energy transmission for other purposes.* . . .	90-kV. system — 75 × 10^6 60-kV. system — 77 × 10^6
4	*Losses in transmission lines*	90-kV. system — 8.5 %. 60-kV. system — 5.5 %.
5	*Maximum voltage drop in transmission lines, excluding exceptional cases.*	90-kV. system — 3 %. 60-kV. system — 5 %.
6	*Measures taken to reduce transmission losses :* a) *by control of load division between generating stations operating in parallel.*	*a)* Programme of the distributi the load between the generatin tions to improve their efficiency
	b) *by extension of the distribution system.* . . .	*b)* Connecting the high tension lin parallel when the operating tions allow it.
	c) *by voltage regulation at various points on the system.*	*c)* Regulating the voltage by mea synchronous compensators fitted automatic regulators.
	d) *by control of the division of reactive current between generating stations.*	*d)* Dividing the wattless current ween the power stations.
	e) *by compensation of reactive current*	
	f) *other steps*	
7	*Steps taken to reduce discharge loss on insulators.* .	None; an ample number of insu is provided : 14 per chain for 220 kV. 9 per chain for 150 kV. 6 per chain for 90 kV. 4 or 5 per chain for 60 kV.
8	*Steps taken to reduce losses due to corona effect.* . .	Large diameter for the high-t conductors. In some very high tage stations, tubes or cables hemp cores are used.
	C. **Traction substations.**	
1	*Number and type of substations in use*	106 — 1 500-V. substations, of wh 81 — with rotary convertors; 2 — with motor generators; 23 — with mercury vapour rect
2	*Equipment of substations*	45 manually-controlled substation 61 automatic substations. 1 to 4 traction sets in each subst Capacity of rotary convertors : 2 × 750 V. : 500 to 1 000 Capacity of converters : 1 × 1 500 V. : 750 to 2 000 Capacity of rectifiers : 1 200 to 2 00 Capacity of motor generator se Generator : 1 000 kW. Synchronous motor : 5 600 kV Allowed overload of the traction s 50 % during 2 hours; 200 % during 5 minutes.
3	*Adaptation of traction sets in service to the actual load in order to reduce losses.*	Yes.

French State Rys.	*Paris-Lyon-Méditerranée (P.L.M.) Rys.*	*Ch. de fer économiques du Nord (France).*
	4	5
...	10 600 kW. during 5 minutes.	...
...	None.	...
46 × 10^6 kWh.	21 × 10^6 kWh.	...
12 × 10^6 kWh.	None.	...
...	Unknown.	...
About 3 %.	About 3 %.	...
Concerns the supply authority.	...	...
...	...	...
...	...	...
...	...	...
...	Synchronous motors in one substation.	...
...	...	...
...	None.	...
...	None.	...
substations, of which : with rectifiers, and transformer.	8 substations, of which : 1 with motor generator sets; 7 with rotary convertors.	2 substations with motor generator sets.
anually-operated substations. bstations with rectifiers entirely utomatic and remote controlled. 4 traction sets in each station. acity of rotary convertors : 1 000 to 1 500 kW. acity of rectifiers : 1 000 to 2 000 kW. rload of new rectifiers : 50 % during 2 hours : 200 % during 5 minutes.	All the substations are manually-operated. 2 to 3 traction sets in each substation. 2 000-kW. motor-generators. 1 000-kW. rotary convertors. Overloads : 50 % during 2 hours. 200 % during 5 minutes.	Local control. 2 traction sets, each of 400-kW. capacity (1-hour rating) in each substation.
Yes.	Yes. Some of the substations are closed down during slack hours.	Yes. Twice each Sunday.

Questions.	Direct-current traction. 1	*P.O.-Midi Rys.* 2
4	*Method used to adapt traction sets to the load.* . .	In manually-operated substatio spare set started up to suit th workings. In the automatic substations, the set is started up by an overloa
5	*Transformer efficiency :* a) *full load and* cos φ = *1.* . . . . . . b) *half load and* cos φ = *1.*	98 to 98.6 %. 97.7 to 98.15 %. In the case of transformers feedi tifiers : 98.2 % and 97.7 % respectiv
6	*Motor-generator set efficiency :* a) *full load and* cos φ = *1.* . . . . . . b) *half load and* cos φ = *1.* . . . . . . *Rotary converter efficiency :* a) *full load and* cos φ = *1.* . . . . . . b) *half load and* cos φ = *1.*	91 % 87 %. 94 to 96 % 91.7 to 93.7 %
7	*Use of rotary converters instead of motor-generator sets in order to reduce losses.*	Yes.
8	*Substitution of mercury vapour rectifiers for rotary converters.*	Yes. (1) Rotary convertors transfer other substations of the same (2) To install larger rectifiers.
9	*Substations equipped with rectifiers :* a) *efficiency of the equipment* . . . . . . b) *methods used to reduce accessory losses.* . . . c) *minimum working temperature* . . . . . . d) *causes of backfires* . . . . . . e) *object of polarized grids.* . . . . . . f) *power factor at full load.* . . . . . . g) *difficulties encountered, due either to deformation of the sinusoidal curve of the primary current, or to undulatory curve of direct current; steps taken to overcome such difficulties.*	Overall, 88 to 93 %. Suitable ventilation of the buil 40° C. This back-firing is not systen For instantaneous protection short-circuits and for regulati voltage. 0.96 at the maximum load of 6 0 (5 min.) for the 6-phase recti Fitting resonant shunts consis capacity elements and tuned in coils for harmonics 6, 12, 18, the substations (frequencies 600, 900 and 1 200 cycles) w it is possible to obtain direct giving practically no interferen low-voltage lines.
10	*Special measures taken and additional apparatus installed in substations to enable regenerative braking to be used.*	In substations with compound rotary converters, the compoun ings are shunted by a contact trolled by relays at the momer is any return current. The p the machines are provided wi 2 anti-compound windings to c sate the action of the shunte pound windings.
	D. **Contact lines.**	
1	*Contact system used*	2 455 km. of track equippe wit head contact line of the ordinar 63 km. equipped with 3rd rail (8

French State Rys. 3	*Paris-Lyon-Méditerranée (P.L.M.) Rys.* 4	*Ch. de fer économiques du Nord (France).* 5
3 times a day in locally-control-l substations. In the others auto-atically, either by current-ope-ted relays or by relays which ke the heating-up of the machi-s into account.	Manually, several times a day.	Manually.
98.4 % 93.5 %	97.15 to 98.1 % 95.8 to 97.8 %	98.1 %. 98.2 %.
None. ... 95.5 % 93.5 %	87.49 %. 80.80 %. 95 %. 92 %	87 %. 82 %. ... ...
...	Yes.	No.
Yes.	...	...
Overall, 88 to 93 %. ulation of cooling water in a osed circuit. ... ich backfires not systematic. None. ... None.	None.	None. ... ...
None.	The compound windings on the field magnets of the rotary-converter short-circuited by a relay-actuated contactor when there is any reserve current.	No regeneration.
rd-rail at the present time.	98 km. of 3rd-rail. 37 km. of overhead contact line.	Overhead contact line.

Questions.	Direct-current traction. 1	*P.O.-Midi Rys.* 2
2	*Steps taken to reduce resistivity of 3rd rail :* a) *use of special conductor material* . . . . . . b) *use of special section* . . . . . . c) *improvement of rail bonding*	Special manganese steel. Double-headed rail. None.
3	*Total copper or equivalent cross section of overhead line and of feeder cables.*	100 to 1 100 mm2.
4	*Paralleling of conductors between substations on multi-track lines to reduce losses.*	Yes.
5	*Unilateral or bilateral feeding of contact line sections between two substations.*	Bilateral.
6	*Use of 4th (return) rail.*	No.
7	*Steps taken to improve return of current through running rails, earth or rails and earth :* a) *bonding used and method of fixing.* . . . . . b) *interbonding of parallel tracks* . . . . . . c) *return-current conductor* . . . . . . d) *earth plates*	Rails electrically bonded. 1. Copper cable bonds fixed by dr 2. Welded connections. On principle every kilomete No. A negative feeder however, i between the entrance and out some spiral tunnels. No.
8	*Approximate losses in contact lines*	About 10 % of the power suppli the substations.
1	**E. Locomotives, motor coaches and other rolling stock.** *Steps taken in recent locomotive designs to reduce current consumption :* a) *dead-weight reduction* . . . . . . b) *motor speed (r.p.m.) at 1-hour rating* . . . . . c) *axle drive.* . . . . . . d) *gear ratio.* . . . . . . e) *reduction of current surges when starting.* . . f) *streamlining*	Installation of meters to intere enginemen in the consumption. No endeavour to do so, so as not duce the adhesive weight. ... Individual. ... ... No.
2	*Experiments with mutators mounted on locomotive.* .	None.

French State Rys.	*Paris-Lyon-Méditerranée (P.L.M.) Rys.*	*Ch. de fer économiques du Nord (France).*
3	4	5
Steel rail 76 kgr./m. type. ... Rails thermit-welded.	Mild steel, 12 microhms-cm2/cm. 50 kgr./m. double-headed rail. Thermit welding in place of copper connections. Welded lengths : about 300 m.	... ...
...	434 mm2.	162 mm2 on 67 % of the length. 200 mm2 on 33 % of the length.
...	Yes.	No multi-track lines.
Bilateral. tion boxes provided half way between each pair of substations.	Bilateral.	Bilateral.
No.	No.	No.
e running rails are insulated from he earth as well as possible. Welded connections.	2 copper connections at each joint.	Welded connections.
e neutral points are connected to nductive connections every kilo-netre.	Equipotential connections every 500 m.	Every 100 m.
No.	No.	Only at the substations.
No.	No.	No earth return.
About 12 %.	17.4 % in 1935.	About 10 %.
No locomotives.	...	No locomotives.
...	No.	...
... ...	600 to 1 010. Individual. 1:2.4 to 1:4.45. No. No.	... ...
...	None.	...

Questions.	Direct-current traction. 1	*P.O.-Midi Rys.* 2
3	*Steps taken in recent motor coach designs to reduce current consumption :*	
	a) *reduction of dead weight*	As recent motor coaches have to as multiple units with the old ches, interchangeability has thought more important.
	b) *motor speed (r.p.m.) at 1-hour rating.*	...
	c) *axle drive*	...
	d) *gear ratio.*	...
	e) *reduction of current surges when starting* . . .	...
	f) *streamlining*	...
4	*Use of ball or roller bearings*	Roller bearings on the traction n of one high-speed locomotive a motor coaches. Roller bearing axle boxes on 22 coaches.
5	*Electric train heating :*	Yes.
	a) *heating system*	Radiators. On trial hot-air cent heating.
	b) *cutting off heating current during starting period*	No.
	c) *control of carriage heating*	Automatic under trial on some trains.
	d) *energy used for heating as a percentage of total used for traction, lighting and heating purposes.*	About 7 to 8 %.
6	*Regenerative braking :*	
	a) *gradients on which regenerative braking is used.*	1 in 100 to 1 in 31.
	b) *total or partial regenerative braking*	750 t. from 120 to 25 km. an hour 1 in 100 and 540 t. from 45 km. an hour down 1 in 31.
	c) *energy recovered in proportion to the train braking work.*	Unknown; regeneration was n adopted for braking.
	d) *increase in weight resulting from the installation of regenerative braking plant.*	About 4.5 t. on 141-t. high-speed motives.

French State Rys.	*Paris-Lyon-Méditerranée (P.L.M.) Rys.*	*Ch. de fer économiques du Nord (France).*
3	4	5
Not investigated.	No motor coaches on the Culoz-Modane line.	...
1 480	...	820
Individual.	...	Individual.
1 : 2.85	...	1 : 5.61.
...	...	...
Not very marked.	...	...
Roller bearings on the traction motors. Under consideration for axle bearings.	Under trial on the motors of a goods locomotive.	Roller bearings on the motors.
Yes.	Coal-fired boilers.	Yes.
Radiators.	...	Radiators.
No.	...	No.
Automatic.	...	By the train staff.
About 13 %.	...	8 %.
None.	1 in 100 to 1 in 31.	No regeneration.
...	Total or partial according to the gradient and the weight to be held.	...
...	Almost entirely.	...
...	5 to 6 tons.	...

Direct-cu

Questions.	Direct-current traction.	*Voies ferrées départementales du Midi.*
		6
	A. General.	
1	*Length of electrified lines, in kilometres :*	
	a) *single track*	101.4
	b) *double track*	...
	c) *multiple track*	...
	d) *together*	101.4 (metre gau
	e) *in course of electrification*	...
	f) *projected*	...
2	*Nominal current voltage*	1 500 V.
3	*Yearly power consumption*	1.15 × 10^6 kWh.
4	*Place where purchased energy (if any) is received.*	In a main station.
5	*Load factor :*	
	a) *at power house or place where power is received.*	6.8
	b) *at substations transmitting to the contact line :*	
	1. *up to 50 000 kWh. per week*	...
	2. *from 50 000 kWh. to 200 000 kWh. per week.*	...
	3. *from 200 000 kWh. to 500 000 kWh. per week.*	...
	4. *more than 500 000 kWh. per week.*	...
6	*Average power factor :*	
	a) *at power house*	0.96
	b) *at substations*	...
7	*Drawing up train timetables taking into account surplus power and load conditions of the electric system.*	No.
	B. Transmission lines.	
1	*Distribution system :*	
	a) *independent*	At 30 kV. from the main stati to the substations.
	b) *joint.*	...
	c) *kind of current*	3-phase, 50-cycle.
2	*Approximate length of transmission lines, in kilometres*	53 km.

stems *(contd.).*

Algerian Rys. 7	*Belgian National Rys. Co.* 8	*Brussels-Tervueren Ry.* 9
163 ... ... 163	... 44 ... 44	7.1 ... ... 7.1 ... ...
3 000 V.	3 000 V.	1 500 V.
27.3×10^6 kWh.	9.5×10^6 kWh.	1.63×10^6 kWh.
At the incoming side of the substations.	At the substations.	At the power station.
4.8 ... ... 3.45 ...	... ... 8.6	12.13 12.5 ... ...
... 0.98	... 0.94	...
No. e Supply Company's power station is adequate for the present.	No.	No. The question is under consideration.
... 90 kV. 3-phase, 50-cycle.	Two substations, each supplied by a separate power station by means of a special line. ... 3-phase, 50-cycle.	At 11 kV. ... 3-phase, 50-cycle.
140 km.	12.2 km.	8 km.

Questions.	Direct-current traction.	*Voies ferrées départementales du Midi.*
	1	6
3	*For the last completed year of operation max. load and energy consumption :* a) *max. power for traction purposes*	900 kW.
	b) *max. power for other purposes*	None.
	c) *energy transmission for traction purposes* . . .	1.15×10^6 kWh.
	d) *energy transmission for other purposes*	None.
4	*Losses in transmission lines*	3 %
5	*Maximum voltage drop in transmission lines, excluding exceptional cases.*	...
6	*Measures taken to reduce transmission losses :* a) *by control of load division between generating stations operating in parallel.*	None.
	b) *by extension of the distribution system.* . . .	...
	c) *by voltage regulation at various points on the system.*	...
	d) *by control of the division of reactive current between generating stations.*	...
	e) *by compensation of reactive current*	...
	f) *other steps*	...
7	*Steps taken to reduce discharge loss on insulators.* .	...
8	*Steps taken to reduce losses due to corona effect.* . .	...
	C. **Traction substations.**	
1	*Number and type of substations in use*	2 substations with rectifiers
2	*Equipment of substations*	Manual control. 2 traction sets, each of 500 k in each substation.
3	*Adaptation of traction sets in service to the actual load in order to reduce losses.*	No, only one set in service, the being spare.

Algerian Rys. 7	*Belgian National Rys. Co.* 8	*Brussels-Tervueren Ry.* 9
13 000 kW. 1 500 kW. 23.7 × 10^6 kWh. 3.74 × 10^6 kWh.	4 575 kW., peak load for a quarter of an hour. ... 9.5 × 10^6 kWh. ...	2 150 kW. 8 kW. 1.57 × 10^6 kWh. ...
Not measured.	Estimated overall at 1.9	2.45 %
Not measured.	2.65 %	3.5 %
A single power station supplies the power. ... ... ith the help of synchronous motors. ...	The power stations are not interconnected.	... ...
None.	None.	...
None.	None.	...
4 substations of which : 3 with rotary converters, and 1 with rectifiers.	2 substations with rectifiers.	1 substation with rectifiers.
Automatic control by clock with contacts. 2 to 3 sets in each substation. apacity : Motor-generators : 2 500 kW. continuous; 3 750 kW. during 3 hours; 7 000 kW. during 5 minutes. Rectifiers : 2 000 kW. continuous; 3 000 kW. during 2 hours; 6 000 kW. during 5 minutes.	3 manually-controlled rectifiers in each substation. Capacity of the rectifiers : 1 500 kW. continuous; 2 250 kW. during 2 hours; 4 500 kw. during 5 minutes; 5 500 kW. during 45 seconds.	3 manually-controlled rectifiers. Capacity : 700 kW. continuous. Overload capacity : 50 % during 2 minutes; 100 % momentarily.
Yes.	Yes.	Yes.

Questions.	Direct-current traction. 1	*Voies ferrées départementale du Midi.* 6
4	*Method used to adapt traction sets to the load.* . .	...
5	*Transformer efficiency :* a) *full load and* cos φ = 1.	...
	b) *half load and* cos φ = 1.	...
6	*Motor-generator set efficiency :* a) *full load and* cos φ = 1.	...
	b) *half load and* cos φ = 1.	...
	Rotary converter efficiency : a) *full load and* cos φ = 1.	...
	b) *half load and* cos φ = 1.	...
7	*Use of rotary converters instead of motor-generator sets in order to reduce losses.*	...
8	*Substitution of mercury vapour rectifiers for rotary converters.*	Rectifiers where installed origin
9	*Substations equipped with rectifiers :* a) *efficiency of the equipment*	Overall, 94.8 to 95.3 %.
	b) *methods used to reduce accessory losses.* . . .	None.
	c) *minimum working temperature*	...
	d) *causes of backfires*	...
	e) *object of polarized grids.*	None.
	f) *power factor at full load.*	...
	g) *difficulties encountered, due either to deformation of the sinusoidal curve of the primary current, or to undulatory curve of direct current; steps taken to overcome such difficulties.*	None.
10	*Special measures taken and additional apparatus installed in substations to enable regenerative braking to be used.*	No regeneration.
	D. Contact lines.	
1	*Contact system used*	Overhead contact line.

Algerian Rys.	*Belgian National Rys. Co.*	*Brussels-Tervueren Ry.*
7	8	9
Automatic in case of overload or the set in use failing.	One rectifier normally in use; a second during traffic rushes.	Put into service manually, according to traffic.
98.5 % 98.2 %	98.5 % 98.4 %	... ...
86.7 % 80.9 %	... ...	... ...
No.	...	No.
No.	...	No.
Overall, 95.8 to 96.8 %. ... ... Nothing has gone wrong since they were put into use. None. 0.97 to 0.95 (rectifier alone). ıe. Wave dampers were coupled on he negative so as not to interfere ıith the telephones.	About 95 % The radiators, fans and vacuum pump are operated automatically. 42° C. Unknown. To cut off the current in the case of backfire. 0.94 (transformer rectifier set). Disturbances in the adjacent telephone lines eliminated by filters at the substations.	95 to 95.2 %. ... 15° C. Temperature too low. Anode caps unscrewed and out of place. None. 0.93 Rather high induction in the telephone line alongside the railway. Nothing done.
thing special in the substations. At he power station, a liquid resistance utomatically introduced absorbs the xcess power regenerated.	No regeneration.	No regeneration.
Overhead contact line.	Overhead contact line.	Overhead contact line.

Questions.	Direct-current traction. 1	*Voies ferrées départementale du Midi.* 6
2	*Steps taken to reduce resistivity of 3rd rail :* a) *use of special conductor material* . . . . . . b) *use of special section* . . . . . . c) *improvement of rail bonding*	... ...
3	*Total copper or equivalent cross section of overhead line and of feeder cables.*	140 mm²
4	*Paralleling of conductors between substations on multi-track lines to reduce losses.*	Single track.
5	*Unilateral or bilateral feeding of contact line sections between two substations.*	Unilateral.
6	*Use of 4th (return) rail.*	No.
7	*Steps taken to improve return of current through running rails, earth or rails and earth :* a) *bonding used and method of fixing.* . . . . . b) *interbonding of parallel tracks* . . . . . . c) *return-current conductor* . . . . . . d) *earth plates*	Copper connections. ... One 200-mm² negative feeder to the voltage drop. No.
8	*Approximate losses in contact lines*	...
1	**E. Locomotives, motor coaches and other rolling stock.** *Steps taken in recent locomotive designs to reduce current consumption :* a) *dead-weight reduction* . . . . . . b) *motor speed (r.p.m.) at 1-hour rating* . . . . . c) *axle drive.* . . . . . . d) *gear ratio.* . . . . . . e) *reduction of current surges when starting.* . . f) *streamlining*	No locomotives. ... ...
2	*Experiments with mutators mounted on locomotive.* .	...

Algerian Rys. 7	*Belgian National Rys. Co.* 8	*Brussels-Tervueren Ry.* 9
.. ..	. . ..	... ...
40 mm² on 8 % of the line. 38 » 33 % » 50 » 53 % » 10 » 6 % »	330 mm².	642 mm² on 50 % of the line. 435 mm² on 50 % of the line.
...	About half way between the two substations.	...
Bilateral.	Unilateral. Bilateral feed is provided for and can be put into use.	...
No.	No.	No.
Copper connections, welded. ... ... Earth plates every 1 000 m.	Copper connections, welded. Every 240 m. No. Earthed at substations alone; the remainder is insulated as well as possible.	Copper connections, welded. Every 200 m. No. No.
About 10 %.	About 6 %.	7.5 %
None. tal weight = adhesive weight. 550 Individual. 1 : 4.38	No locomotives.	One locomotive for goods working. Not required. 880 Individual, with elastic drive. 1 : 5.06 ... ...
None.	...	None.

Questions	Direct-current traction.	*Voies ferrées départementales du Midi.* 6
3	*Steps taken in recent motor coach designs to reduce current consumption :*	
	a) *reduction of dead weight*	No special steps.
	b) *motor speed (r.p.m.) at 1-hour rating.*	850
	c) *axle drive*	Individual.
	d) *gear ratio.*	1 : 4.06
	e) *reduction of current surges when starting* . . .	...
	f) *streamlining*	...
4	*Use of ball or roller bearings*	Roller bearings on the motors.
5	*Electric train heating :*	
	a) *heating system*	Yes.
	b) *cutting off heating current during starting period*	Radiators.
	c) *control of carriage heating*	No.
	d) *energy used for heating as a percentage of total used for traction, lighting and heating purposes.*	By the train staff. 5 %
6	*Regenerative braking :*	No regeneration.
	a) *gradients on which regenerative braking is used.*	...
	b) *total or partial regenerative braking*	...
	c) *energy recovered in proportion to the train braking work.*	...
	d) *increase in weight resulting from the installation of regenerative braking plant.*	...

Algerian Rys. 7	*Belgian National Rys. Co.* 8	*Brussels-Tervueren Ry.* 9
No motor coaches.	No special means used.	...
...	1 100	880
...	Individual with spring drive.	Individual.
...	1 : 2.87	1 : 3.87
...	...	...
...	Front and rear of each set of four vehicles streamlined.	. .
No.	Roller bearings on the motors and in the axles boxes of the motor coaches and trailers.	Roller bearings on the motors. No roller-bearing axle boxes.
No.	Yes.	Yes.
...	Hot air central heating.	Radiators.
...	No.	Yes, to reduce the power paid for at the 1/4 hour rate.
...	Automatic control by thermostats. Still unknown.	By the train staff. 8 %
. .	No regeneration.	No regeneration.
1 in 40.	..	...
Partly on 1 in 40 gradients and wholly on 1 in 52 gradients.	...	...
90 %	...	...
8 tons.	...	...

Direct-cur

Questions.	Direct-current traction.	*Netherlands Rys.*
	1	10
	A. General.	
1	*Length of electrified lines, in kilometres :* a) *single track*	...
	b) *double track*	235
	c) *multiple track*	...
	d) *together*	235
	e) *in course of electrification*	...
	f) *projected*	...
2	*Nominal current voltage*	1 500 V.
3	*Yearly power consumption*	80.5×10^6 kWh.
4	*Place where purchased energy (if any) is received.* .	At the power station and at th transformer stations.
5	*Load factor :* a) *at power house or place where power is received.*	4.35 to 6.
	b) *at substations transmitting to the contact line :*	
	1. *up to 50 000 kWh. per week*	...
	2. *from 50 000 kWh. to 200 000 kWh. per week.*	...
	3. *from 200 000 kWh. to 500 000 kWh. per week.*	...
	4. *more than 500 000 kWh. per week.*	...
6	*Average power factor :* a) *at power house*	...
	b) *at substations*	0.85 minimum.
7	*Drawing up train timetables taking into account surplus power and load conditions of the electric system.*	No.
	B. Transmission lines.	
1	*Distribution system :* a) *independent*	At 10 and 25 kV.
	b) *joint*	At 50 kV.
	c) *kind of current*	3-phase, 50-cycle.
2	*Approximate length of transmission lines, in kilometres*	At 25 kV.— 56.5 km. At 10 kV.—152.6 km. At 5 kV.— 7.2 km.

stems *(contd.).*

Dutch East Indies Rys. 11	*Piedmontese Tramways Co.* 12	*Northern of Spain Rys.* 13
48 31 ... 79	120 120	223 180 ... 403
... ...	... ...	193 ...
1 500 V.	Accumulators.	3 000 V. (Pajares section). 1 500 and 1 650 V. on the other sections.
10×10^6 kWh.	0.8×10^6 kWh. (primary).	72×10^6 kWh.
At the substations.	At the substations.	At the substations.
...	1 (constant charging of the accumulators).	...
About 3	... ...	... 4 3.7 ...
... 0.9	... 0.85	... 0.985
No.	...	No.
... At 70 kV. 3-phase, 50-cycle.	... ... 3-phase, 50-cycle.	... at 22.25 and 3 kV. 3-phase, 50-cycle.
100 km.	...	Do not belong to the Norte Railway.

Questions.	Direct-current traction.	*Netherlands Rys.*
	1	10
3	*For the last completed year of operation, maximum load and energy consumption :* a) *max. power for traction purposes*	21 390 kW. during 1 hour.
	b) *max. power for other purposes*	...
	c) *energy transmission for traction purposes* . . .	80.5×10^6 kWh.
	d) *energy transmission for other purposes.* . . .	...
4	*Losses in transmission lines*	2.45 %
5	*Maximum voltage drop in transmission lines, excluding exceptional cases.*	5 to 10 %.
6	*Measures taken to reduce transmission losses :* a) *by control of load division between generating stations operating in parallel.*	None.
	b) *by extension of the distribution system.* . . .	...
	c) *by voltage regulation at various points on the system.*	...
	d) *by control of the division of reactive current between generating stations.*	...
	e) *by compensation of reactive current*	...
	f) *other steps*	...
7	*Steps taken to reduce discharge loss on insulators.* .	...
8	*Steps taken to reduce losses due to corona effect.* . .	...
	C. **Traction substations.**	
1	*Number and type of substations in use*	18 substations : 1 with motor-generator sets 17 with rectifiers.
2	*Equipment of substations*	1 to 4 traction sets per substati Capacity of transformers : 1 000 kW. continuous ; 3 000 kW. during 5 minutes. Capacity of rectifiers : 1 000 to 1 200 kW. continuous ; 4 000 to 4 800 kW. during 40 s 17 automatically and locally con substations.
3	*Adaptation of traction sets in service to the actual load in order to reduce losses.*	No.

Dutch East Indies Rys. 11	*Piedmontese Tramways Co.* 12	*Northern of Spain Rys.* 13
10 000 kW. Unknown. 10×10^6 kWh. Unknown.	... ...	... ...
Unknown.	...	...
Unknown.	...	...
oes not concern the railway.	... ...	... ...
...	...	...
...	...	...
substations : 2 with motor-generator sets; 2 with rectifiers.	3 substations : 2 with motor-generator sets; 1 with rotary convertors.	23 substations with rotary convertors. 2 substations with motor-generator sets.
Local control. traction sets in each station. apacity : Converters, 1 500 kW. Rectifiers, 1 000 kW.	...	Local control. 1 to 3 traction sets in each substation. Capacity of the rotary convertors : 1 500 kW. continuous; 2 250 kW. during 2 hours; 4 700 kW. during 5 minutes. Capacity of the motor-generator sets : 1 900 kVA. continuous; 2 850 kVA. during 2 hours; 4 700 kVA. during 5 minutes.
No. One group in service in each substation.	...	The two traction sets in each substation can be run in parallel according to requirements.

Questions.	Direct-current traction. 1	*Netherlands Rys.* 10
4	*Method used to adapt traction sets to the load.* . .	...
5	*Transformer efficiency :* a) *full load and cos φ = 1.* . . . . . . b) *half load and cos φ = 1.*	... ...
6	*Motor-generator set efficiency :* a) *full load and cos φ = 1.* . . . . . . b) *half load and cos φ = 1.* . . . . . . *Rotary converter efficiency :* a) *full load and cos φ = 1.* . . . . . . b) *half load and cos φ = 1.*	 90 % 86 % ... ...
7	*Use of rotary converters instead of motor-generator sets in order to reduce losses.*	No.
8	*Substitution of mercury vapour rectifiers for rotary converters.*	No.
9	*Substations equipped with rectifiers :* a) *efficiency of the equipment* . . . . . . b) *methods used to reduce accessory losses.* . . . c) *minimum working temperature* . . . . . . d) *causes of backfires* . . . . . . e) *object of polarized grids.* . . . . . . f) *power factor at full load.* . . . . . . g) *difficulties encountered, due either to deformation of the sinusoidal curve of the primary current, or to undulatory curve of direct current; steps taken to overcome such difficulties.*	 95 % None. 20° C. Insufficient vacuum. Polarised grids only in some rect. ... None.
10	*Special measures taken and additional apparatus installed in substations to enable regenerative braking to be used.*	...
1	D. **Contact lines.** *Contact system used*	Overhead contact line.

Dutch East Indies Rys. 11	*Piedmontese Tramways Co.* 2	*Northern of Spain Rys.* 13
...	...	Manual.
... ...	0.97 % 0.95 %	98.5 % 98.4 %
... 0.65 on the average.	0.85 % 0.80 %	89.2 % (cos φ = 0.9). 84.5 % (cos φ = 0.9).
... ...	0.93 % 0.90 %	94.6 % 91.7 %
No.	Yes.	No.
No.	...	No rectifier in use.
90 % on the average. None. 35° C. Nothing has gone wrong. None. ... uction in the telephone line made it necessary to install filters.	... ...	... ...
No regeneration.	...	Provision of a current reversing relay for each group of two rotary converters, which shunts the series excitation of the main field magnets whilst regenerating.
Overhead contact line.	...	Overhead contact line.

Questions.	Direct-current traction.	*Netherlands Rys.*
	1	10
2	*Steps taken to reduce resistivity of 3rd rail :* a) *use of special conductor material*	...
	b) *use of special section*	...
	c) *improvement of rail bonding*	...
3	*Total copper or equivalent cross section of overhead line and of feeder cables.*	490 mm².
4	*Paralleling of conductors between substations on multi-track lines to reduce losses.*	In the substations and section b
5	*Unilateral or bilateral feeding of contact line sections between two substations.*	Bilateral.
6	*Use of 4th (return) rail.*	No.
7	*Steps taken to improve return of current through running rails, earth or rails and earth :* a) *bonding used and method of fixing.*	Copper connections welded.
	b) *interbonding of parallel tracks*	Every 150 m.
	c) *return-current conductor*	None.
	d) *earth plates*	None.
8	*Approximate losses in contact lines*	10 %
	E. Locomotives, motor coaches and other rolling stock.	
1	*Steps taken in recent locomotive designs to reduce current consumption :*	No locomotives.
	a) *dead-weight reduction*	...
	b) *motor speed (r.p.m.) at 1-hour rating*	...
	c) *axle drive.*	...
	d) *gear ratio.*	...
	e) *reduction of current surges when starting.* . .	...
	f) *streamlining*	...
2	*Experiments with mutators mounted on locomotive.* .	...

Dutch East Indies Rys. 11	*Piedmontese Tramways Co.* 12	*Northern of Spain Rys.* 13
...	...	...
...	...	...
...	...	...
350 mm².	...	214 mm² on the 3 000-V. electrified lines. 370 mm² on 70 % and 513 mm² on 30 % of the 1 500-V. double-track electrified lines.
Each line is separate.	...	Yes.
Bilateral.	...	Bilateral.
No.	...	No.
Welded connections.	...	100 mm² copper connections.
Every 300 m.	...	Every kilometre.
None.	...	A 100 mm² additional return wire on the 3 000-V. electrified section.
None.	...	None.
Unknown.	...	Unknown.
...	No locomotives.	...
olling stock over ten years old.	...	...
...	...	800 to 1 075.
..	...	Individual.
...	...	1 : 3.43 and 1 : 4.484.
...	...	...
...	...	No, speed limited on lines with steep gradients.
...	...	No.

Questions	Direct-current traction.	*Netherlands Rys.*
	1	10
3	*Steps taken in recent motor coach designs to reduce current consumption :*	
	a) *reduction of dead weight*	All-welded steel construction. I metals used for fittings only.
	b) *motor speed (r.p.m.) at 1-hour rating.*	1 520
	c) *axle drive*	Individual.
	d) *gear ratio.*	1 : 2.25
	e) *reduction of current surges when starting* . . .	No special steps.
	f) *streamlining*	On motor coaches built for 150 an hour.
4	*Use of ball or roller bearings*	Roller bearings on motors for years; roller bearing boxes on ne motor coaches and trailers.
5	*Electric train heating :*	
	a) *heating system*	Yes. Hot air central heating on the new coaches.
	b) *cutting off heating current during starting period*	As a rule the heating is not cut
	c) *control of carriage heating*	Automatic control by thermost
	d) *energy used for heating as a percentage of total used for traction, lighting and heating purposes.*	5 to 7 %.
6	*Regenerative braking :*	
	a) *gradients on which regenerative braking is used.*	No regeneration.
	b) *total or partial regenerative braking*	...
	c) *energy recovered in proportion to the train braking work.*	...
	d) *increase in weight resulting from the installation of regenerative braking plant.*	...

Dutch East Indies Rys. 11	*Piedmontese Tramways Co.* 1	*Northern of Spain Rys.* 13
...	8 wheeled-motor coaches. No.	...
...	600	1 334
...	Individual.	Individual.
...	1 : 5.2	1 : 3.21
...	...	...
...	...	No, speed below 100 km. an hour.
Roller bearings on some motors.	Ball bearings on the motors. Roller bearing axle boxes.	Roller bearings on the motors of motor coaches; will be used also on motors of the locomotives under construction.
No. (The trains are not heated.)	Yes, the motor coaches only. Radiators.	Heating by steam heating vans except the motor coaches. Radiators.
...	No.	No.
...	By the train staff.	By the train staff.
...	...	...
No regeneration.	No regeneration.	
...	...	Total at 20 km. an hour.
...	...	6 % of the total consumption for traction purposes.
...	...	1 750 kgr. (1 500/65 V. motor generator group for exciting the traction motors).

Alternat

Questions.	Single and 3-phase traction.	*Swiss Federal Rys.*
	A. General.	
1	*Length of electrified lines, in kilometres :*	
	a) *single track*	1 036
	b) *double track*	1 063
	c) *together.*	2 099
2	*Kind of current :*	Single-phase.
	a) *voltage*	15 kV.
	b) *frequency*	16 2/3 cycles.
3	*Yearly energy consumption*	518 × 10^6 kWh.
4	*Place where purchased energy is received.*	At the substations.
5	*Load factor :*	
	a) *at power house or place where power is received.*	2
	b) *at substations delivering to the contact line :*	
	1. *up to 50 000 kWh. per week*	9 to 12.
	2. *from 50 000 kWh. to 200 000 kWh. per week.*	6 to 9.
	3. *from 200 000 kWh. to 500 000 kWh. per week.*	4 to 6.
	4. *more than 500 000 kWh. per week*	2 to 4.
6	*Average power factor :*	
	a) *at power house*	0.7 to 0.62.
	b) *at substations*	0.9 to 0.8.
7	*Drawing up train timetables taking into account surplus power and load conditions of the electric system.*	No.
	B. Transmission lines.	
1	a) *independent*	At 132, 66, and 33 kV.
	b) *joint.*	...
	c) *kind of current*	Single-phase, 16 2/3 cycles.
2	*Approximate length of transmission lines, in kilometres.*	At 132 kV. — 268 km. At 66 kV. — 844 km. At 33 kV. — 129 km.
3	*For the last completed year of operation :*	
	a) *max. load for traction purposes*	130 000 kW.
	b) *max. load for other purposes*	...
	c) *energy transmitted for traction purposes*	445 × 10^6 kWh.
	d) *energy transmitted for other purposes*	4.5 × 10^6 kWh.
4	*Losses in transmission lines*	5.9 %.
5	*Maximum voltage drop in transmission lines, excluding exceptional cases.*	12 %.
6	*Measures taken to reduce transmission losses :*	
	a) *by control of load division between generating stations working in parallel.*	Divided between two groups of hydro-electric stations according t grammes.
	b) *by extension of the distribution system*	...
	c) *by voltage regulation at various points on the system*	In two substations by means of ind regulators.
	d) *by control of the division of reactive current between power houses.*	Inversely as the load on the stati

rrent systems.

ernese Alps (Bern-Loetschberg-Simplon) Rys.	*Rhœtian Ry.*	*Andalusian Rys.*
223 27 250	277 (metre gauge). ... 277 (metre gauge).	30 ... 30
Single-phase. 15 kV. 16 2/3 cycles.	Single-phase 11 kV. 16 2/3 15 cycles.	Three-phase. 6 kV. 25 cycles.
29×10^6 kWh.	15.5×10^6 kWh.	0.9×10^6 kWh.
the principal distribution points.	At the supply points.	...
... 6 4	3.4 ... ... 3.4 ...	6 ... ...
... 0.82 to 0.9.	... ...	0.85 ...
No.	No.	...
At 15 kV. ... Single-phase, 16 2/3 cycles.	The power stations are located near the railway.	At 6 kV. ... Three-phase, 25 cycles.
A. 15 kV.—19.5 km.	...	At 6 kV.—0.5 km.
20 to 22 000 kW.	79 000 kW.	6 000 kW. ... ...
5 %	...	...
...	...	...
.. .. No. ...	Divided between two power stations. ... No. ...	One station, belonging to the railway. ... .

Questions	Single and 3-phase traction.	*Swiss Federal Rys.*
6 (contd)	e) *by compensation of reactive current*	By completing the ampere load of quency converter intended to industrial load.
	f) *other measures*	Use of the running rails and the as conductors in transmitting current.
7	*Steps taken to reduce discharge loss on insulators* . .	None.
8	*Steps taken to reduce losses due to corona effect.* . .	None.
	C. **Traction substations.**	
1	*Number and type of substations*	3 main substations. 22 transformer substations. 8 transformer boxes.
2	*Equipment of substations*	*a*) Main substations: Local control, 2 to 4 transf (132 to 66 kV.), of 12 000 kVA. city (hourly rating). *b*) Transformer substations: Semi-automatic control, 2 to 4 formers (66 to 16 kV.) of 4 00 65 000 kVA. capacity (hourly ra *c*) Transformer boxes: Local control, 1 transformer 16 kV.) of 4 000 kVA. ca (hourly rating). Overload capacity of transformers for 5 minutes. Continuous capacity: 75 % of the ca at the hourly rating.
3	*Adaptation of traction sets in service to the actual load in order to reduce losses.*	No.
4	*Method of adapting traction sets to the load.* . . .	...
5	*Transformer efficiency :* a) *full load and cos* $\varphi = 1$. . . . . . b) *half load and cos* $\varphi = 1$.	97.7 %. 98 %.
6	*Efficiency of motor generator sets :* a) *full load and cos* $\varphi = 1$. . . . . . b) *half load and cos* $\varphi = 1$.	89 %. 84 %.
7	*Production of current at the contact line voltage, to avoid transformer losses.*	Direct feed of the 15-kV. contact l the alternators of two power st
8	*Use of mutators to convert 3-phase current into single-phase.*	No.
	D. **Contact lines.**	
1	*Total or equivalent section of overhead contact lines and feeder cables.*	220 mm² on 1 775 km. 110 mm² on 283 km.
2	*Bonding in parallel of contact lines on multi-track sections.*	Yes. Delayed-action automatic separat one of the lines is out of order.
3	*Unilateral or bilateral feeding of contact line sections between two substations.*	Mostly unilateral to prevent any cussion of short circuits on s substations.

rnese Alps (Bern-Loetschberg-Simplon) Rys.	*Rhætian Ry*	*Andalusian Rys.*
No. ...	Division of the reactive current between the Thusis power station and the Bevers substation, the motor-generator sets in which act as phase advancers.	... ...
None.	None.	...
...	...	...
3 main distribution points.	1 substation.	None.
No equipment of transformers or rotaries.	2 motor converter sets each consisting of : One 900 h.p. three phase asynchronous motor ; One 1 000 kW. direct current generator ; One 1 300 kVA. single phase alternator in continuous service ; One 20 T. flywheel ; 2 buffer batteries each of 1 250 ampere-hours capacity. Hand operation.	...
...	...	...
...	...	...
... ...	... ...	... ...
... ...	... ...	... ...
...	Yes.	Yes.
No.	No.	...
200 and 150 mm².	135 mm².	2×50 mm².
Yes.	Yes.	...
Unilateral.	Bilateral.	...

Questions.	Single and 3-phase traction.	*Swiss Federal Rys.*
4	*Steps taken to improve return of current through running rails, earth, or again through rails and earth :* a) *bonding used and fixing method*	50-mm² welded copper bonds.
	b) *interbonding of parallel tracks*	...
	c) *return current conductor*	Only when connecting the trac to the substation.
	d) *earth plates*	A large earthing system in th substations alone.
5	*Approximate losses in contact lines.*	About 4 to 5 %.
	E. Locomotives, motor coaches and other rolling stock.	
1	*Steps taken in recent locomotive designs to reduce current consumption :* a) *reduction of dead weight*	No particular steps.
	b) *motor speed (r.p.m.) at 1-hr. rating*	700 to 750.
	c) *axle drive*	Individual spring drive.
	d) *gear ratio.*	1 : 2.57 and 1 : 3.47.
	e) *reducing current surges when starting*	At 12.5 % of the maximum curr
	f) *streamlining*	No.
2	*Experiments with mutators mounted on locomotive.* .	...
3	*Steps taken on recent motor coach designs to reduce current consumption :* a) *reduction of dead weight*	Special rolled steel sections and li alloys in the construction of the
	b) *motor speed (r.p.m.) at 1-hr. rating*	1 500
	c) *axle drive*	Individual.
	d) *gear ratio*	2.96
	e) *reducing current surges when starting*	At 22 % of the maximum curre
	f) *streamlining*	Quite marked on light motor coach up to 140 an hour speeds.
4	*Use of ball or roller bearings*	On some passenger vehicles.
5	*Electric train heating :* a) *heating system*	Yes. Radiators.
		On new carriages : central heatin hot air.
	b) *cutting off heating current during starting period*	No.
	c) *control of carriage heating*	By the train staff.
	d) *energy used for heating as a percentage of total consumption for traction, lighting and heating purposes*	Automatic on the new coaches 8.5 to 9.5 %.
6	*Regenerative braking :* a) *gradients on which regenerative braking is used.*	1 in 37.
	b) *total or partial regenerative braking*	Braking the locomotive alone; ab 30 % of the weight of the trai
	c) *energy recovered in proportion to the train braking work.*	About 25 %.
	d) *increase in weight resulting from the installation of regenerative braking plant.*	3 to 4 % of the weight of the locom

rnese Alps (Bern-Loetschberg-Simplon) Rys.	*Rhætian Ry.*	*Andalusian Rys.*
50 mm² welded copper bonds.	6 mm. diameter iron wire bouds.	Copper bonds, wedged in.
...	...	...
...	...	...
Used in some places.	None.	None.
...	...	4 %
None.	None.	...
...	...	...
Individual.	Rod drive.	...
Up to 1 : 5.76	...	...
increasing the number of control steps up to 24 for 4 500 H.P.	...	...
No.	No.	...
...	...	...
nstruction of light motor coaches.	No motor coaches.	No motor coaches.
...	...	...
Individual.	...	...
...	...	...
...	...	...
e, speed below 100 km. an hour.	...	...
n the motor bearings and in the axle boxes.	...	...
Yes.	Yes.	No.
Radiators.	Radiators	...
No.	No.	...
By the train staff.	By the train staff.	...
omatic on the light motor coaches.		
10 to 15 %.	10 %	...
No, rheostatic braking.	With some locomotives.	Yes.
...	1 in 28 to 1 in 22.	1 in 100 to 1 in 40.
...	35 % of the weight of the train.	Total.
...	About 30 %.	...
...	2 400 kgr., i.e. about 4 % of the weight of the locomotive.	...

[621. 33]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

13th SESSION (PARIS, 1937).

QUESTION VI.

Methods and devices used, in connection with electric traction, to save current between the supply side of the power station and the driving wheels (feeders, substations, tractors), and in particular the use of mercury rectifiers.

REPORT

(Austria, Germany, Denmark, Norway, Sweden, Finland, Poland, Hungary, Czechoslovakia, Jugoslavia, Bulgaria, Rumania, Greece, Turkey),

by E. R. KAAN,

Engineer, Ministerial Councillor, Director for Electrification, Austrian Federal Railways.

I. — Introduction.

Whereas steam traction in railway working has more than a century of experience behind it, and may be considered to be now fully developed, and, in spite of considerable progress in many directions in recent years — appears to have reached a certain finality, electric traction may be called a child of the twentieth century, and having grown out of its infancy, is now in an advanced stage of development. The fundamental questions, for example, the king of current, can be considered as solved although recently very promising attempts have been made to introduce new ideas in this field. In the many remaining questions, especially those of a manufacturing nature, we see still further developments before us. Electric traction is not indifferent to the progress being made in electrotechnics but continues to be influenced by it in many ways.

The International Railway Congress Association, at its Twelfth Session in Cairo, in 1933, dealt with some very important electric traction problems (Question V).

It is certainly very gratifying and of the greatest value to many of the affiliated Administrations that the Association has continued to interest itself in this subject and has included in the agenda for the XIIIth Session the question enunciated above, which is the logical development of the elaborate investigations made by the reporters to the Cairo Congress. While in addition to some detailed questions, the main problems considered at Cairo were rather of a general character, it is now intended to enquire specially into the methods and equipment in connection with the large

amount of plant installed between the power-house and the driving axles of the locomotives and motor coaches.

The three reporters appointed for Question VI jointly sent a questionnaire to the member Administrations. Based on the answers which they received from the countries allotted to them, tables given in the appendices were compiled under two main heads, namely : — alternating-current railways, and direct-current railways.

First of all it should be noted that of the countries covered by our report, Bulgaria and Finland possess no standard-gauge lines operated electrically. Also that the railway authorities of Jugoslavia, Rumania and Turkey report no electric traction, but are seriously considering its introduction. Since the schemes in the three last mentioned States are very far advanced, it was happily possible to take these countries into account with those already possessing electrically-operated Systems. The *Association of Swedish Privately-owned Railways,* with its head office in Stockholm, has intimated that its electric lines are of too small importance to be considered. Further the diagrams supplied by the Administrations of their electrified lines are not included in this report in order to save space; these lines, however, are known in most cases, as particulars have been published in the technical press.

Question VI can be divided into five sections, under which economies can be grouped : — General, transmission lines, substations, contact lines, locomotives and motor coaches. The questionnaire was divided up in the same way. Each section mentioned includes from 6 to 12 questions, so that 41 questions in all were asked.

II. — General remarks with special reference to rectifiers.

It was pointed out in the Introduction that the question as to which type of current was most suitable in each individual case could be considered to be more or less settled, although in recent years some new systems have been successfully introduced or are now under trial with every promise of their adoption.

Each of the different systems of electric traction has its own particular advantages. This explains why the Railway Authorities, not only in different countries but in one and the same country, have adopted different kinds of current. The resulting diversity, in conjunction with the theoretical developments that have taken place, has provided practical data on the different systems and has shown their advantages and disadvantages. This co-existence of different systems, especially in the case of the small private railways, has on the other hand such disadvantages as regards their future amalgamation into larger railway groups, that endeavours have been made to standardise the system used on the main lines by rebuilding or other means. For this reason, for example, the *Nordmark-Klarelfvens* privately-owned Railway in Sweden, at present using 16-kV. 25-cycle current, will after the completion of its own power-house use 16 2/3-cycle current. The locomotives now in service have therefore been equipped for the change from 25 to 16 2/3 cycles.

We see no reason to add to the considerations as to the kind of current developed at the XII Congress at Cairo, and in particular in the report of Messrs. HUBER-STOCKAR and ECKERT. The only reason for mentioning this here is that there is always the possibility of one or other Administration deciding to adopt on a larger scale than in the past some new system in conjunction with rectifier plant. In the case of A.C. lines more than on D.C. lines a measure of this kind would involve alterations which might

be considered as a radical change of system.

As worded, question VI asks the reporters to give special consideration to the mercury-arc rectifier and we will begin by giving a short survey of the development of this subject, which obviously cannot dealt with it exhaustively.

As the equipment provided to distribute power to the motor vehicles when running must be as simple as possible, and as it is desirable to have a flexible motor, the evolution of the types of current used for electric traction was on lines opposed to the direct use on a large scale of the power-houses and transmission lines used for the general distribution of electrical energy. The demand for an efficient method of converting three-phase current of industrial frequency into traction current can be regarded, therefore, as a highly important problem, the solution of which will have a great influence on the economics of electric traction.

Whereas in the early stages of the development of the supply of electrical energy to electrified railways, many attempts were made to avoid any form of transformation, because of its initial drawbacks, by generating energy in special power-houses belonging to the railway, rotary converters had to be used, especially on the smaller railway systems which for financial reasons could not have an independent self-contained supply. The comparatively cheap rotary converter is preferred as a rule to the more expensive motor-generators although this meant abandoning independent regulation of the line voltage. On A.C. railways, as is shown by the example of the *Swedish State Rys.* the synchronous-synchronous rotary converter has been successfully introduced. The rigid dependence of the frequency on the three-phase network can have unfavourable effects in places where the traction requirements are no longer of secondary importance relatively to the general demand on the three-phase network. In such cases, the asynchronous-synchronous rotary converter with suitable regulating notches on the three-phase side provides complete control not dependent on the voltage and frequency of the two networks, and is therefore especially suitable when a formerly independent traction system has to be coupled up with a three-phase system. This type of conversion is used on the *Norwegian State Rys.* and on one line of the *German State Rys. (Reichsbahn).*

In spite of the favourable operating results obtained with rotary converters, the economic results were extremely disappointing, chiefly because of the high energy losses, reaching 20 % and over. Efforts were immediately made to improve the conversion process by developing new types which would reduce these losses.

For D.C. railways, this question may be looked upon as solved by the successful development of the mercury arc rectifier. Helped by the quite analogous requirements of many tramways, the conversion of three-phase current into D.C. has developed from the initial stage with rotary converters, until the invention of powerful rectifiers able to fully meet the requirements of a method of converting electrical energy with the least losses, at a reasonable first cost and with very great reliability. The average efficiency of rectifier plant to-day is from 94 to 96 %, which is attributable to the favourable shape of the efficiency curve; this only shows an appreciable increase in the percentage losses at very small loads, while all demands exceeding a fifth of the nominal load are met with excellent efficiency. The outstanding position which the rectifier in general occupies to-day on D.C. railway systems is further due to its extraordinary insensitiveness to overloading, which makes it possible to deal with peak loads up to three to four times the normal rating. This unusual overload capacity

of the rectifier is due to the design of the anode of valves which have reached a state of perfection which a few years ago, would have been thought impossible. Further advantages are the little care and attention needed; the easy manipulation, the easy running in parallel without synchronising, and the small wear.

The satisfactory results obtained by using rectifiers have been still improved by using grid control. As is known, this regulation rests on the discovery by the American Nobel Prize Winner, LANGMUIR, that in a mercury arc rectifier fed with alternating current, fitted with a grid between the two electrodes, when the anode is charged positively relatively to the cathode, the current starts to pass instantaneously if the grid is positively charged, while the arc does not strike even when the anode is positive, if the grid is negative.

Although attempts have been made, by suitable modification of the grid charge to suppress the arc once formed, before the period of zero current, they have not given practical results, yet the power of producing ignition at any moment has opened the way to a series of marked improvements which have made of the rectifier a converting apparatus indispensable on all D.C.-operated railways.

First of all, the introduction of grid control has made it possible to regulate the D.C. voltage within the desired limits, independently of the incoming primary A.C., as in the case of motor-generator sets, in which the compounding varies with the current. The distributor, which determines the position of ignition and therefore the value of the D.C. voltage, is usually dependent on the cathode current, so that the D.C. voltage corresponds at all times to the secondary load. This method of controlling the voltage possesses, it is true, a disadvantage, in that it has an unfavourable effect on the primary power factor, and gives pulsating D.C. voltage. Whilst the lowering of the power factor on the incoming side increases the losses through the greater consumption of wattless current, the pulsations of the direct current voltage can only be compensated by enlarging the filters (smoothing impedance coils or screen filters) involving increased capital expenditure as well as increased smoothing losses. The general practice is so to govern the D.C. voltage by the grid control that at the usual load of about 50 to 100 %, the anodes are regulated to cause ignition at the usual point while at smaller loads the grid control is used. On the other hand, for loads exceeding the rating, every kind of compounding has been abandoned in favour of allowing the voltage to drop sufficiently, which simultaneously prevents the peak loads becoming too marked. An additional means for improving the voltage control is provided by the use of tapping points on the primary winding of the incoming transformer, provided the load is more or less regular and the number of commutations remains small.

In addition to the simple, smooth voltage regulation, the grid control has the important advantage of quickly stopping the passage through the valve of the half-waves following a short-circuit peak current, and of thus causing an extremely sudden break in the short-circuit; as a result the heating effects at the place where the short-circuit occurs are considerably diminished and, on the other hand, the circuit breakers arranged for breaking these short-circuit currents are relieved completely of their original function. The short-circuit currents are broken in the simplest manner by already using the first current impulse following the short-circuit in order to supply instantaneously to the grid control the voltage required to suppress the arc so that further development of the short-circuit

current is prevented almost at its inception.

If this use of grid control is more suitable for lowering the maintenance costs, by preventing heavy damage due to short-circuits in the distribution lines, and by reducing wear on the circuit breakers, the use of grid-controlled rectifiers as alternating rectifiers i.e. to transform D.C. into A.C. has brought with it direct advantages as regards savings in energy consumption, particularly in those cases in which energy can be regenerated when trains are running down gradients.

The alternating rectifiers are either excited by the line or self-excitors are fitted. In the first case the A.C. system acts as regulator and ensures the passage of the current from one anode to the next, as well as exciting the main transformer. On the other hand, for self-excited alternating current rectifiers, the conversion is effected without the help of regulating synchronous machines, that is independently, the frequency being maintained constant between rather wide limits by suitable control devices — the grids can be provided with automatic or remote control.

Some railways are equipped at the present time with alternating current rectifiers for regenerated energy (inverters) much to their commercial advantage, although regeneration with grid-controlled alternating rectifiers is somewhat lower in efficiency than the A.C.-D.C. rectifier.

The A.C. rectifier is nevertheless in a fair way to replace the rotary converter as successfully as its close relation the D.C. rectifier — in spite of the short time it has been in existence. One of the chief reasons is that the transition from the direct to the alternating rectifier has been worked out in a perfectly flexible and smooth manner, without failure, by taking suitable precautions.

In view of the advantages of transmitting energy long distances as high-tension direct current, the rectifier, used both as direct and alternating rectifier, has been further developed in recent years for even higher voltages, so that voltages as high as 60 000 can be handled at the present time by one rectifier without difficulty. Higher overhead line voltage on D.C. railways, therefore, now only depends on the further development of the direct current traction motor which has stopped at a maximum line voltage of 3 000. Even in this direction the development of the high-voltage rectifier opens new vistas by the use of the *direct-current transformer.*

The high-tension D.C. is transformed first of all in an alternating rectifier into a symmetrical multi-phase current which, after the foregoing transformation, is led to a D.C. rectifier where it is transformed back to D.C. of corresponding voltage. The direct voltage, and with it the output, is regulated continuously by grid control in the two valves.

There can be no doubt that this briefly described development, when translated into practice, will make the high-tension D.C. system the ideal system for feeding the railways in the future.

Meanwhile, investigations have been undertaken in order to overcome the difficulties the compounding of traction motors opposes to the voltage being further increased, by using valve-controlled D.C. motors. The principle of this motor is based on the use of the rectifier for transforming the D.C. into multi-phase A.C., the motor acting as regulator, the number of revolutions and direction of rotation of which can be altered at will by the excitation, and by altering the moment at which the arc is struck. In this motor the commutator is thus replaced as it were by the controlling valve, which by means of a contactor puts the different stator phases of the motor in circuit in turn. A disadvantage of this motor is that it requires a special D.C. motor to start

it, which considerably lowers the prospect of its being used in railway operation.

This disadvantage is avoided by the commutatorless single-phase motor which works on similar lines, the running winding of which is also in the stator, whilst the field winding, fed by slip rings, is housed in the rotor and the full cathode current flows through it. A special importance attaches to this novel use of the rectifier on locomotives in that it makes it possible to supply single-phase current of any frequency to one and the same locomotive, so that the locomotives could be used on railway systems with different frequencies.

If under these conditions, the rectifier is about to take its place in the A.C. railway field, the attempts to convert industrial frequency current into lower frequency single-phase current by means of efficient *frequency converters* should be specially noted. By the use of a special assembly, the phase and frequency linkage between three-phase and single-phase systems can be avoided; in other words, differences of phase and frequency can be allowed to exist between the two systems without making the passage of wattless current impossible, so that by means of the frequency converter another frequency can be given to the single or multi-phase alternating current. The frequency converter thus makes possible flexible interconnection of systems of different frequencies for the mutual exchange of energy.

It is true that the problems which are to be solved for this phase and frequency conversion are, from the purely physical standpoint, considerably more difficult than those which had to be solved in the case of the direct or alternating rectifiers which did not need a special energy accumulator.

Conversion of three-phase current into single-phase pulsating current of a different frequency postulates the occurrence of periodical variations of the power impressed upon the three-phase system in the absence of suitable storage, in consequence of the pulsating tapping on the single-phase side. In the first experimental plant, no attempt was made to avoid these pulsations which led to irregularities in the current and voltage curves on the three-phase side being looked upon as permissible if the proportion of the railway load to the total load of the three-phase system did not exceed a certain value (about 20 %). It has become clear futhermore that the unsymmetrical load in the three-phase system, set up by the working of the frequency converters causes further losses in the three-phase system, and in addition, owing to the harmonics in the current taken from the three-phase side, a considerable drop in the power factor.

The development of frequency converters, therefore, proceeds in the direction of balancing out the known disadvantageous reactions of the single-phase peak load by the use of suitable electrical storage devices (reactance coils and condensers). These storage devices are used at the same time to supply wattless current to the single-phase side, so that their use is similar to that of the mechanical storage of rotary machines. Such a frequency converter therefore exacts the same work from the three-phase network as an ordinary rectifier, so that the values of the power factor on the three-phase side in contrast to the frequency converter without storage are comparatively high.

A plant of this kind has been in operation at the Pforzheim substation of the *Deutsche Reichsbahn* for some time. It is used for coupling up the South-German railway systems at 110 kV. 16 2/3 cycles with the three-phase lines of the Baden power station, 110 kV. 50 cycles, and has a rated capacity of 3 000 kVA when $\cos \varphi = 0.7$. In order to be able to use them on the different voltages of the two systems, the frequency converters are provided with a rather large

number of tappings. The frequency converter only provides for the transmission of the active current, the direction and magnitude of which can be regulated with the help of the control apparatus independently of the frequency slip of both systems. The wattless current on the single-phase side, on the other hand, is supplied by a battery of condensers, which is divided into sections that can be inter- and disconnected at will, and allows the wattless energy to be regulated approximately, fine regulation of the wattless power being effected by controlling the time the arc is struck on the anodes. This method of conversion presupposes the existence of special regulating machines on the single-phase side. Experiments are, however, in progress which aim at transforming the three-phase current into single-phase independently, as with the frequency converter without storage.

This shows that in a surprisingly short time the rectifier has shown itself suitable for very many uses in the electric traction field. Today it dominates the D.C. railway field as a continuous and alternating converter, and by its advantages has almost completely eliminated the rotary convertor. Thus the rectifier is to be found on the *Danish, Polish* and *Czechoslovak State Rys.*, and in the electrification schemes of the *Rumanian State Rys.*, whilst in all the countries covered by this report motor-generators are used only in one plant of the *Austrian Federal Rys.*

The latest development of the rectifier, which is far from being final, concerns its use as a frequency converter so that its advantages can be made available on the A.C. railways. Although this use has not yet emerged from the experimental stage, the results justify the hope that the object of changing the frequency efficiently and thereby removing one of the chief obstacles in the way of the standardisation of the equipment for feeding the railways using A.C. will be attained shortly.

III. — Means of effecting economies in energy consumption between the delivery points or the power house and the driving axles.

Before dealing in detail with this question, it must be remembered that when any method of reducing energy losses is considered, its economic value must be ascertained. In each case it is necessary to find out if the saving in energy is such as to justify the increase in capital expenditure thereby involved, or to balance another drawback, often difficult to evaluate, such as for example, hindrances to smooth operation. The tolerable energy losses on a railway represent, therefore, a compromise between many considerations.

The diversity of the technical, natural, and financial conditions between countries, due to the very nature of things, should be regarded as one of the chief causes of variation in the selection by the various Administrations of the means for reducing the energy losses to the minimum economically possible. This is why the present report confines itself to dealing with the technical means used and to reporting their advantages with regard to energy savings.

If we now consider in detail the energy losses beginning with those in electric traction stationary plant, we can divide them roughly into two main groups, one of which comprises those losses which are constant whatever the load, and which therefore can be referred to as the no-load losses, whilst the losses of the second group are closely bound up with the transmission load, which therefore can be called the live-load losses.

Amongst the no-load losses, the induced losses come first, due to the incomplete insulation of the equipment. Their extent depends directly on the

working voltage and the state of insulation of the equipment. These induced currents are in phase with the useful voltage so that energy losses occur. Under the conditions prevailing in practice, these energy losses are relatively unimportant, and may be neglected as a rule in computing the losses. At the same time the induced currents in unfavourable circumstances can increase to some extent, especially in the case of very bad insulation causing frequent earthing, when they directly disturb the working of the equipment.

Lines specially exposed to such losses are those in the neighbourhood of chemical industries, metallurgical works, or large areas of water, also contact lines of electrified railways with mixed working, owing to the smoke from the steam locomotives, and finally lines in large industrial centres. In areas subject to these influences special precautions must be taken, as for example by strengthening or doubling the insulation in order to keep down the induced losses, and at the same time the risk of earthing.

A further means of reducing the induced loss consists of limiting as much as possible the number of supports of the electrical conductors. Every increase in the span, therefore, not only diminishes the number of possible sources of faults, but is at the same time an excellent method of reducing the induced losses.

To the same group belong also the radiation losses due to the well known corona effect. They are not, however, of much importance except at voltages of 100 kV. and upwards. Apart from the chemical composition and the density of the air surrounding the line, their amount depends chiefly on the conductor diameter, diminishing rapidly with increasing conductor diameter, and finally becoming negligible.

Non-radiating fittings together with the largest possible cross-section of conductor are therefore used for high-tension lines, and in those places where the full cross section determined by the minimum diameter cannot be economically adopted, hollow cables are used which at the same time have the advantage of a very favourable current distribution. Steel and aluminium cables also represent, in this connection, an excellent means of cutting out radiation losses.

In the group of losses varying with the load, the energy losses are brought about by the necessity of maintaining the electrical and magnetic field in all the conductors and machines. They are due therefore to the various no-load currents which have to be considered as pure power currents, or leading or lagging components according to the direction of the current vectors. In A.C. equipment with voltages up to about 100 kV., the inductive no-load current considerably outweighs the capacity and purely resistance effects, on which account the power factor of A.C. equipments as a rule lies in the inductive region. Specially noteworthy is the small alteration of the value of the no-load current in proportion to the variations of the useful current, i.e. the power component. The effect of this is that the power factor at the outgoing side of the power stations rises rapidly as the useful load increases, and often reaches values considerably above the average power factor for the year. For similar reasons, a general decline of the power factor occurs as the useful load approaches the no-load condition.

Since the commercial value of energy transmission can be influenced very seriously by the no-load losses, it is most important to prevent them. The available means are those which aim at directly reducing the no-load losses, and also those by which these losses are only reduced indirectly as by a rational local distribution of means for the production of the wattless current or by shortening the distance between the points of production and consumption.

The no-load losses always include a more or less large number of fractional losses, the effect of which is only felt as a whole, so that it is easy to underestimate their influence or to consider their value unchangeable. Actually the insufficient appreciation of these losses is largely to blame for the comparatively bad load factor of A.C. Railways. We must ascribe to it today in the first place the constantly increasing demands for reductions in the weight and prices of electrical machinery, which savings unfortunately are sometimes obtained at the expense of the little noticed no-load currents. As a proof of how little it is realised that the no-load currents have reached at last an excessive proportion, we would refer to the fact that the highly alloyed steel laminations in dynamos have only been in use a few years in spite of the progress that has been made in their use in the construction of other types of electric machinery.

The object of the steps taken to reduce the losses in the iron in order to effect a general improvement in the magnetic properties of the laminations is also that of the efforts of electrical machinery manufacturers to contribute from their side to the reduction of the no-load losses. In this connection the excellent results obtained in transformers by using iron cores with the butt joints between the yoke and core plates replaced by interlaced joints as well as, by reductions in the value of the no-load current due to a smaller air gap in the rotaries. This fact is illustrated more clearly by the following example of the practice of the *Austrian Federal Rys.*

This Administration possesses a number of substations erected about ten years ago, in which the transformers show about 7.5 % of no-load current. Two years ago, when electrifying the Tauern line, further substation transformers were obtained by the same Administration of approximately the same capacity as the existing ones. The no-load current of these units was reduced to 1.45 % of the rated current, thanks to a series of precautions such as those mentioned above. The absolute current saving amounted to 4 amps. per unit. Since about 30 voltage transformers of the old type are in service on the system, the no-load current of these units compared with that attainable today appears to be about 120 amps. too high. If it is borne in mind that this current saving corresponds to a no-load loss of about 6 000 kVA., which throughout the year is to be produced by the generators in the power house and transmitted over the distributing system to the transformers, the importance of the no-load losses in railway plant is obvious.

In addition to these precautions already to be observed in the design and construction of electric railway equipment, there are many methods for reducing the no-load current, and with it the no-load losses in the system. The first and simplest means is to rigorously adapt the equipment to the varying loading conditions, whilst of course meeting the requirements of a regular and uninterrupted railway service by building up adequate reserve power capacity. In order to be independent of the vigilance of the staff, new switches were designed and tested in practical working by which the number of units in use at any time is adjusted automatically to the load.

The constant control of the division of the wattless current between the supply stations is another point of special importance, and it should be so carried out that its economic efficiency is always in harmony with the need for maintaining an adequate voltage. It is usual, therefore, to work on the principle of producing the excitation current as near as possible to the point of consumption in order to keep the transmission losses as low as possible. Groups of synchronous machines working as phase advancers are used mainly for

this purpose; they are inserted at the centre of gravity of consumption of wattless current and so relieve to a very great extent the transmission of a very large proportion of the wattless current. In addition, on low-frequency systems the losses through an unsatisfactory load distribution caused by keeping up the voltage can be reduced as for example by using choking coils in the lines coupling up power houses working in parallel. The high inductive resistance of these coils equalises the variations in the reactive load and at the same time increases the dynamic stability when working in parallel. From the point of view of transmitting wattless loads, a highly efficient method is that in which the necessary wattless current is normally produced on the site, such as what occurs in synchronous-synchronous converter substations, or with current systems taking from the line a load almost free from induction.

As an remarkable example of this type may be mentioned the Kandó system of the *Royal Hungarian State Rys.*, in which part of the wattless current needed by the substations can even be supplied from the locomotives.

The no-load losses also include the energy used for dissipating the heat set up in the electrical machinery and transformers. The heat is conducted away by water or air which has to be pumped to the parts to be cooled. In this connection too there are a number of energy saving devices which regulate the pumps to suit the load, in such a way that when it is small and natural cooling is satisfactory, the pumps are automatically cut out.

Finally the losses depending on the load are of capital economic importance, because of the high values they can reach, especially with peak loads. To prevent them exceeding commercially allowable values, the cross-sectional areas of the conductors must be carefully checked over, not only as regards permissible voltage drops, but more particularly as regards their economic efficiency relatively to the expected energy losses, and these investigations should be extended to all possible cases of load distribution between power stations working in parallel. Any hesitation as regards dimensions or ill-chosen economy in first cost can have serious effects on the subsequent behaviour of the plant especially if — as is usually the case — the estimated current consumption through unexpected traffic rushes, is largely exceeded.

Excessive power losses are reflected unto the contact line by the serious voltage drops accompanying them. The dimensions of the conductors must be calculated very carefully. Consequently, not only the contact line but also the suspension cables and the auxiliary conductors sometimes run in parallel with the contact line are made from material of high conductivity, preferably copper or when a high mechanical strength is required at the same time, bronze of high conductivity.

The return through the rails also requires attention and the solution adopted should always consider the nature of the ground in the neighbourhood of the formation of the railway. Experience shows that on A.C. railways cross connections between the parallel roads meet the requirements, and that bonds at the rail joints are usually of little value, as with heavy loads the resistance falls off much at these points.

Owing to the lines of rails being so widely extended there is very little resistance to the flow of the current to earth so that special track earthing devices are only needed in very exceptional cases, the more so that the cost of providing additional earth connections such as earthing plates, pipes or bands is out of all proportion to the results obtained. When the ground is unfavourable, i.e. when rocky or when there is water at a great depth, the best prac-

tice is to use special earth return lines, either laid directly in the ground or freely hung on the posts of the trolley line.

The arrangement of the equipments supplying the energy can vary very considerably according to any special conditions, and influences to a marked degree the extent of the losses under load. This applies especially to A.C. lines with which we will deal first of all. The simplest system is to generate the traction current in one or more power stations, usually working in parallel, and transmit it over lines, usually belonging to the railway, to the substations where the voltage is transformed to a usable figure and fed to the contact lines. With this system of supply the power losses depending on the load are usually limited to the transmission line losses and to the transformation losses in the substations; the yearly average of these losses is about 10 to 16 % at most of the energy produced. The total losses in the fixed plant, i.e. inclusive of the losses in the contact lines, with this system may be taken as some 20 % of the quantity of power supplied by the generating station. Unfortunately this relatively low loss has to be paid for by a proportionately high capital cost of the power stations and transmission lines, which is only justified when the quantity of power is such as to guarantee the economic use of the capital invested in the power plant.

When these conditions are not fulfilled, and in addition the price of power is relatively low owing to favourable generating conditions, as for example on the *Swedish State Rys.*, the capital cost can be diminished by taking advantage of existing generating stations and transmission lines for three-phase current to feed A.C. railways. A particular feature of this system is that, before it is fed to the overhead line, the three-phase industrial frequency current must undergo a conversion which is much more costly, owing to the heavy load losses and the higher capital cost of the substations, than a mere transformation of the voltage. This costly conversion is only avoidable with special systems producing first of all 50-cycle single-phase current; such is, for example, the case with the Kandó system on the *Royal Hungarian State Rys.* and the *Höllental* line now operated experimentally by the *Reichsbahn*. The question as to whether these methods should be adopted in particular cases depends upon special circumstances.

On all D.C. railways, conversion with its heavy losses was inevitable at the beginning, when the transmission of D.C. over long distances and the transformation of this current was almost impossible. We mentioned in an earlier chapter the particularly good results obtained during the last ten years as regards the more efficient conversion of three-phase current into D.C., and we will merely note here that the energy losses during this transformation have been reduced to about a third of what they were originally, through the improvements in rectifiers.

The situation is much less favourable on low-frequency A.C. lines which up to the present, when fed from the three-phase system, are almost compelled to use motor-generators. In this case the transformation losses are still some 25 % of the power received in a usable form on the contact line, and in conjunction with a much higher capital cost than when the voltage has merely to be transformed, forms a very serious obstacle to many railways having their power plants interconnected with those of the general distribution network. Now, the exceptionally high losses under load is the very reason why this new method will not be adopted until these losses have been reduced in the same degree as on D. C. railways, by the progress made in the construction of rectifiers. Unfortunately it is not yet

possible to predict with any certainty when the elaborate investigations and experiments now being carried out in this connection will enable rectifiers to be used in the practical working of main-line railways.

There are available a certain number of methods enabling losses due to the load to be reduced as much as possible. Besides the permanent control of the distribution of the load and the hardly possible adjustment of the traffic so as to make the load uniform, the first thing to do is to link up on a large scale the existing contact lines or to interconnect parallel distribution lines. The fact that this method, which seems so simple, has not been adopted in every case to reduce power losses is undoubtedly due first and foremost to the serious drawback, from the operating point of view, arising in the case of failures on interconnected systems, in spite of the high degree of improvement in the design of relays. These drawbacks have a particular importance in the case of the contact lines, which are readily upset, so that many railways prefer a simpler and more easily controlled method of protection against mishaps, rather than a more complete interconnection of the contact lines.

As the voltage must be maintained regularly between the allowed limits, even under peak loads, to meet service requirements, the voltages in the generating stations are usually regulated so as to vary automatically with the load. This is usually done by overcompouding in proportion to the useful current supplied; it is also an excellent method of reducing the energy losses which increase considerably at peak loads, so that it ought to be used to the extent fullest possible, especially on much overloaded systems.

As regards the *motor vehicles*, current can be saved by reducing friction losses, friction due to air resistance as well as that of the revolving parts of the machines. As regards the latter, for some time ordinary bearings which until recently were used exclusively, are being replaced by ball bearings, cylindrical roller bearings or barrel-shaped roller bearings. In recent years, many railways have adopted roller bearings not only for goods wagons with high axle loads, but also for railcars and their trailers. The results expected with heavy streamlined steam locomotives, with the axles as well as the driving and coupling rods fitted with roller bearings can ge applied usefully to electric locomotives. In addition to the lower rolling resistance especially at starting, which will save current, there is a further advantage in the fewer cases of hot boxes.

A still greater current saving is obtained by reducing the *air resistance*, which absorbs at high speeds, such as 100 km. (62 miles) per hour and over, a very considerable part of the power developed by the engine, as it increases with the square of the speed. When the front of the power vehicle and the end of the train are streamlined the air pressure on the front of the train and the vacuum at the end are already reduced appreciably. Although the air resistance at the front and tail ends of the train remain approximately the same for different train lengths, this does not apply to the resistance from the sides of the vehicles, especially that of the underside of the vehicles, with their driving and running gear. Tests made with a 14-wheel model of a steam locomotive, with the driving gear alone encased, shows a power saving of some 90 H.P. at 150 km. (93 miles) an hour; when the spoke wheels were replaced by plain wheels or when they were closed in, a further saving of some 10 H.P. was effected. The surface of the train taken as the sum of the part surfaces perpendicular to the running direction becomes considerable on long trains. Consequently, it is not enough to

give the locomotives and railcars a streamlined shape, the trailers must be given a similar shape, and the gaps between the vehicles must be closed. True, rolling stock of this kind can then only be used on what are called streamlined trains. Electric locomotives cannot be completely streamlined, as the roof, in addition to the pick-up gear, carries various electrical equipment which cannot easily be covered in. In addition there are two driver's compartments so that it is difficult to provide an entirely shut-in passage between the locomotive and the train. Contrariwise electric motor coaches, are no more difficult to deal with than any other such vehicles. When the front end is rounded off all projections removed from the side faces, and the sides brought down as near as possible to the rails, the air resistance is considerably reduced. As an example of the good results obtained with streamlining, tests carried out at 150 km. (93 miles) an hour, show a saving of some 400 to 500 H.P. on the locomotives.

In addition to the so called permanent losses mentioned above, there are also temporary losses. Suitable measures can be taken to avoid such losses, but in each case the current saving should be compared with the cost involved in saving it. The suggestion has naturally been made of reducing the strong current required when starting a train, by reducing the *train heating,* even to a relatively small extent. When dealing with passenger services with frequent stops, this method can give considerable relief. The annual consumption for train heating in Central Europe amounts to about 8 % of the total consumption; related to the period during which the train must be heated the consumption in round figures can be 20 % of the corresponding total energy used.

Welding is used on a very large scale in building rail motor cars, passenger carriages, and goods wagons. The weight of the vehicles is much reduced and consequently considerable current savings are effected. In conjunction with welding, higher grade steel is used throughout, consequently lighter standard and special rolled sections. The front ends of passenger carriages are provided with stiffening parts and oppose high resistance to impact, Rivetting is replaced by welding in the bogie frames, the headstocks are welded to the solebars, the body framing and sides to the pillars. In some cases to save still more weight, light types of wheels with hollow axles are used. The tare weight of the vehicles is reduced by all such means, and ultimately the dead weight of the train. Parts which have to be replaced for wear or for general repairs, as for example the brake gear and axle guards, are bolted or rivetted as in the past. The tests carried out by many railways to ascertain the strength of welded parts have had entirely satisfactory results; they show that welded joints are equal to or better than the corresponding rivetted joints. In such tests the side walls and the body frame were not only tested in compression, but the details were tested under bending and torsion, i.e. as regards the properties which become of special importance as regards strength in case of accidents.

Welding is also used in the construction of locomotives in very many parts, both for assembling the bogie frame and the underframe, in which the use of new steels has given a weight saving of 15 to 20 %; it is also used in the body framing, the motor casing, and the transformer covers, the geared wheels, and the hubs.

In order to reduce the tare weight, *light constructional materials* are also used, rivetted together, welded, or brazed. The higher cost of these materials is largely made good by various advantages; consequently these materials are used in rolling stock construction to such an extent that in many cases steel is only used for the wheels and axles,

axle boxes, springs, and brake gear. Light metals are also used for covering the body, for the floor, and the interior fittings. The reduction in tare weight in passenger coaches in which steel is only used for the solebars and bogies can be as much as 40 %. Carriages and rail motor cars of this kind of construction have shown great strength in accidents, such as collisions ; the damage was confined to the ends, the passenger compartments not being affected.

Light materials are also used for covering in the ends of the locomotives, for the body sheeting, the ventilating ducts, motor cases, bearing covers, brush carriers as well as gear cases and collector gear. On heavy machines the saving in weight can be as much as 6 tons.

However, this new method of construction is still more important for rolling stock than for locomotives, in particular for passenger coaches where the ratio of the tare to the useful load can be improved considerably.

Another method of reducing the weight is to use *light wheel* sets. Disc wheels have been used for a long time in four-wheeled passenger coaches, but only recently for steam locomotive carrying wheels. They are formed of two steel plates with a void between them. The practical conclusions to be obtained from these tests can be applied in electric motor coach construction. The reduction in weight due to using high-grade steel disc wheels and hollow axles is very large, as the weight of the wheels under passenger carriages represents some 10 to 15 % of the total weight.

The question of *regenerative braking* is also connected to the current saving problem, whether it is used on fairly easy lines but with many stops, or on lines with long, steep gradients. As is known, with regenerative braking, the traction motor acts as a generator and feeds current back to the supply network, so that there is a transformation into electric power of kinetic energy during braking for slowing down and potential energy when running on a slope at uniform speed. Besides the more or less large current saving, regenerative braking has two good features : the wear of the tyres and brake shoes is less and there is greater safety, as the mechanical brakes can be kept chiefly in reserve. At the present time regenerative braking is possible with all systems of current. The power available can be fed into the distribution network or can be used for auxiliary services on the locomotive, such as heating, or driving a compressor, or it can be absorbed in resistances. When the energy is fed back into the line, and cannot be absorbed locally, it has to be absorbed by the substation; the feeding back of this energy and its absorption by the substation must take place without any surges and in a perfectly flexible manner. With the D.C. rectifiers used on railways, this condition is suitably met by the quite separate division of the regenerated and supply energy between the machines and apparatus provided for this purpose, for frequently a train braked by regeneration may be running down a gradient and the energy regenerated can only be absorbed irregularly by another train which is shunting at the same time, so that the power not absorbed by this latter train must be sent back to the substation.

Regeneration is only possible on single-phase locomotives fitted with series motors when additional equipment and special connections are provided. Usually a special shunt excitor with reaction coils in the field circuit are used, or separate excitation by single to three-phase converters. One drawback must be pointed out, namely that the locomotive braked by regeneration gets its wattless current through the contact line, which affects the power factor. Owing to the heavy weight of the auxiliary equipment on the locomotives and their

relatively high cost. regenerative braking is little used on single-phase railways.

IV. — Discussion of the replies to the questionnaire.

1. General.

All the main-line A.C. railways take advantage of the facility with which A.C. can be transformed. The power stations and substations are linked together by transmission lines; the line voltage is a multiple of that of the generators and energy consumers, so as to improve the economical character of the transmission. The same considerations also apply to the D.C. railways of *Denmark, Poland* and *Czechoslovakia,* where the D.C. substations are also fed by the generating stations through transmission lines. It is only in a few cases, for example the Salzkammergut line of the *Austrian Federal Rys.* that a section of contact line is fed directly by the generating station. As a result, the contact line is generally divided up into a certain number of separate feeding sections which has the advantage that any service failure such as drops in voltage due to heavy demands for power or short circuits does not exercise any direct effect on the generating plant. In addition it is much easier to localise faults.

The load factor of the generating station, the ratio of the maximum load to the average load over the year, was only given by the *German, Austrian* and *Norwegian Rys.* Information as to the load factor of the substations has been supplied by the *Hungarian* and *Czechoslovak Rys.* The *Hungarian State Rys.* which operate the longest 15-kV. 50-cycle contact line give a constant of 5 for the annual load factor of the substations, with a power factor of 1.0 to 0.96 (lagging).

On the other hand, in the substations of the *Austrian Federal Rys.* it has been found that the load factor in the substations lies between 3.8 and a maximum of 13.7. The relatively great difference between these values is due to the difference in traffic density and the character of the lines. As a rule the substations feeding a level section carrying dense traffic are in use a longer time, and consequently their load factor is small relatively to that of substations feeding mountain regions where the traffic is relatively light.

Generally speaking the replies confirm the well known fact that the load factor varies inversely to the area of the system. The *Reichsbahn,* for example, has found that its Bavaria-Wurtemberg system has the same load factor, i.e. 2.3, as the *Austrian Federal Rys.,* although the *Deutsche Reichsbahn* with its annual consumption of some 261 million kWh., uses nearly double the power used by the *Austrian Federal Rys.* who use 134 million kWh. These figures only give, of course an idea of the magnitude; nonetheless, the conclusion to be drawn from this is that the load factor of the main-line railways tends towards a minimum of about the value mentioned above, and that any further extension of the system would not lower it. This is a most important observation, especially in the original layout of new lines, as it provides a very simple means of finding the maximum power which must be provided for.

In the absence of suitable control equipment, the value of the average annual power factor of the different railways can only be given as an estimate. Apart from the numerical exactitude of the different values of the power factor, it is very difficult to compare the information given in view of the diversity of its sources. It seems, moreover, that the numerical value of the annual average power factor of low-frequency A.C. railways, measured at the power stations varies round about 0.7, whereas the Kandó system on the *Hungarian State*

Rys. works on 50-cycle frequency with a load almost free from induction.

On railways taking current from a three-phase system through rotary converters, like the *Turkish State Rys.*, the power factor on the three-phase side is about 0.9 at the substation. From this point of view it should be stated that the *Swedish State Rys.*' substations with synchronous converters work with a power factor of 0.7 leading; these converters supply therefore a wattless current lagging to the three-phase network and have a very valuable effect on the economic value of the transmission of power and on maintaining the voltage in the primary three-phase system.

A rather surprising fact is that all Railways have replied negatively to the question dealing with rearranging the train services and timetables to improve the load conditions. Perhaps the conclusion may be drawn that the capacity of the power plant of these railways has been so far sufficient to meet all the service needs without any restriction. Besides it appears difficult to adapt the timetables to the requirements of the generating plant, even in a small way, however valuable it may be, and the chief reason is that trains running in connection with those on neighbouring railways must be taken into account. The timetables could only be adapted on a large scale to suit the power available in the case of railways worked for one particular purpose, such as those specially engaged in mass goods transport. Sometimes, however, this object may be partly realised by running the goods trains of secondary importance at the hours of the day or night when the traffic is lightest.

2. **Transmission lines.**

When transmitting the power between the power stations and the substations, transmission lines used exclusively for electric traction purposes are employed primarily by the Administrations which have adopted low-frequency A.C. This group of railways includes the *Reichsbahn* which operates in south Germany an extensive system of single-phase transmission lines at 110 kV. 16 2/3 cycles, then the *Austrian Federal Rys.* whose electrified lines west of Salzburg are fed by a transmission system at 55 kV. belonging to the railway, and the *Norwegian State Rys.* which feed part of their electrified lines by means of a 50 kV. system, and lastly the *Swedish State Rys.*, who in the north of the country supply a mining railway from a 50 kV. system of some length.

The possession of transmission lines by the railway has several advantages, of particular importance when several power stations or suppliers of current are working in parallel. Apart from greater freedom in establishing the cost of current and a certain latitude in the choice of the source of the power, or outside suppliers, an independent transmission system, especially when it covers a large area, provides the means of reducing the transmission losses by direct and continual action on the distribution of the useful and wattless current demand.

When the power is supplied by a certain number of power stations or from other sources, these economies are subordinate to the possibility of constantly supervising, from a central point, the working of the railway. With this object, the *Austrian Federal Rys.* propose to equip a central observation station with equipment for remote control so as to distribute quickly and economically the load of the five generating stations belonging to the Administration which feed in parallel a common transmission network. While the automatic distribution of the useful load is usually confined to the turbine regulators of the hydro-electric power stations working in parallel, the distribution of

wattless current is closely linked up with the need for maintaining the voltage and is controlled by automatic voltage regulators so arranged as to give as economic a distribution as possible of the wattless load. The action of the voltage regulators is not always sufficient to prevent costly fluctuations in the wattless current. These variations can be reduced by using anticompounding depending on the demand for wattless current by which the voltage of the generating station is regulated according to the wattless current produced, so that when the supply of wattless current increases the voltage is automatically reduced to the permissible limit. Another method of improving the transmission conditions and the efficiency of the lines between the generating stations and the generators working in parallel consists of inserting supplementary reactance coils, as installed by the *Austrian Federal Rys.* on their 55-kV. transmission line which feeds the Arlberg railway line. In spite of the considerable reaction of these coils, which is 4×10 ohms, this measure has reduced the transmission losses so that at nearly twice the load the losses are not more than before these coils were fitted. In order to reduce the voltage drop and the power losses in the supply line, the same Railways use on one line transformers which automatically raise the feeder voltage as the load increases.

The voltage losses in these transmission lines vary between 7 and 20 %, the maximum value including the losses in the substations. A good part of these losses is always made good by compounding the voltage in the generating station, so that the actual differences in voltage at the supply points are appreciably less than would be expected from what we have just said.

The ends of heavily loaded lines are sometimes aided by synchronous phase advancers. Generating stations inside the centre of load may become of much greater economic value if they are employed as auxiliary phase advancers, as shown by the Spullersee power station of the Austrian Federal Rys.

The information supplied by the various railways as regards power losses in transmission lines is mostly based on estimates. These losses are given as 7 to 10 % and are relatively rather greater than those considered economically allowable on three-phase systems.

Unlike transmission lines solely used for transmitting traction current, lines employed at the same time for general purposes and consequently usually working as industrial-frequency three-phase are of less interest to the Railways. They are usually in the hands of the power suppliers, whereas the Railway Administrations are simply users and can therefore exercise no decisive influence either on the production of the primary current nor on the distribution before the current is brought into their substations.

3. Substations.

The differences between the various systems of current are shown much more clearly in the substations, where the traction energy is converted into the final form required by the motors, than in any part of the transmission system on electric railways. In considering the losses in the substations, the simple transformation of alternating current is the one which gives the least loss. At full non-inductive load, these losses are not more than 1.5 % with modern transformers, and only increase a fraction of 1 % at half load. Relatively to the older types of voltage transformers the efficiency has usually been improved very considerably, so that there is little room left for further progress.

Substations with mercury arc rectifiers, wherein the loss at full load is on the average about 4 %, are in much the same position. The total losses in

rectifier substations, including the voltage transformation on the primary side, at full load is about 7 % and at half load about 8 %.

The position is rather more unfavourable as regards frequency conversion, for which the rotary converter is the only available method at the present time. Conversion properly speaking in this case still means losses of about 12 %, so that when the double voltage transformation which is always necessary is added, the total loss under full load will be about 15 %. The *Swedish State Rys.* report the annual average efficiency of their conversion stations as being 82.3 %, but this figure does not take into account the step-down losses on the three-phase side.

Direct production of the voltage on the contact line in generators, which would avoid the additional voltage transformation losses on the secondary side of the substations, is not used by any of the railways consulted, for the reason that they do not wish to expose the generators directly to short-circuits in the contact lines. More importance is consequently attached to the possible danger of upsetting the service than to savings in power losses that would be obtained if the contact line were fed directly.

There seems to be some unanimity as regards the need of varying the number of units in use according to the load, although here again security of operation is the more important. At times these units are put into or out of service automatically according to the load acting at any moment, this being done for example in the rectifier substations of the *Danish State Rys.* As regards the frequency of these operations, the *Polish State Rys.* report that they take place 2 or 4 times a day.

This last Administration has also effected certain economies by only running the water cooling pumps for heavy loads and the vacuum pumps when running several sets of rectifiers in parallel.

Grid polarisation is used in all modern rectifier plants; this is done in some cases to prevent the serious consequences of backfires. The *Danish State Rys.* also use polarised grids for maintaining the D.C. voltage at a constant figure.

The addition of equalising filters is considered by the *Danish State Rys.* to prevent interference with telephone circuits.

So far no special equipment for regenerating current has been provided in substations fitted with rectifiers. The use of such equipment is specified in the schemes of the *Jugoslav* and *Rumanian State Rys.*

4. Contact lines.

On the Railways consulted the current is taken to the motor vehicles by a contact line arranged above the track. Alternating current contact lines the working voltage of which is a multiple of that of D.C. lines are naturally more heavily insulated, and for equal capacity use a wire of smaller section than the direct current lines which are lightly insulated, but can carry stronger current, so that on sections with much traffic two contact lines in parallel have to be provided. None of the Railways we are dealing with uses the third-rail; nor do any of them use a fourth rail for the return. For technical reasons in connection with the distribution and to reduce the voltage drop, these Railways in all cases use auxiliary lines on the single-track lines when these are only fed on one side.

The isolators between the sections fed by the substantions can be either open or closed. In the first case each section of the contact line situated between two substations is fed on one side with the advantage that any possible disturbance in the contact line remains limited to a relatively small

section and only affects one substation; in addition short circuits are isolated at once by the substation since the feed circuit breaker of the substation is not preceded by another circuit breaker connecting the feed areas.

On the other hand there is the drawback of rather serious voltage drops. In the second case the isolators of the feed areas are closed. In case of earthing, these switches must re-open automatically and break the connection and only then can the feeder switch isolate the defective section of line. The section cannot be isolated so quickly as in the first case when the isolators are open; as the defect must cause several switches to work so that the time before the section is isolated is rather longer, and with it the damage caused by the disturbance. An advantage of this bilateral feed is, on the other hand, that the loss of voltage is smaller. On the *Deutsche Reichsbahn,* in ordinary working the sections of contact line are fed on both sides by neighbouring substations, with the switches of the feed area closed; but unilateral feed with the switches open is preferred by the *Swedish State Rys.* and by the *Austrian Federal Rys.* This seems to show that the advantages and drawbacks compensate each other in practical working. An exception based on technical reasons should be mentioned here : the *Hungarian State Rys.* on which the feed zones of the substations remain electrically separated in an absolute manner, seeing that each substation is attached to a different phase of the three-phase distribution. On the running road the consecutive sections of single-track line are normally supplied by an additional conductor by means of which they are fed on both sides by the stations. All the railways without exception separate electrically, throughout the zones fed by the substations, the contact lines of double-track under normal distribution conditions; the contact lines are therefore not coupled in parallel although it is possible to do so. The advantage is that a short-circuit occurring in one contact line has no reaction on the neighbouring line. If the lines are connected together, this parallel coupling reduces the voltage drops by about one half, but against this it takes more time to locate faults. Coupling the contact lines in parallel is only found on the *Hungarian State Rys.*

As a general rule, the cross section of the contact wires on the main lines is greater than in sidings, as the contact lines have to carry the major part of the power and also have to stand more wear than those on the sidings. Copper is used everywhere for the contact line; as regards the feeder cables, copper is used, or for economic reasons steel or bronze, or two-metal wires. Electric bonds at the rail joints are far from being used by all railways. Except the *Norwegian State Rys.* which still use them generally, they are only found on the D.C. railways of *Denmark, Poland* and *Czechoslovakia.* As is shown by the results obtained in service, the use of electric bonding does not seem to be necessary on A.C. railways, where the strong stray currents which might be found outside the permanent way are less harmful to the water mains in the ground and to the metal parts of the cables than is the case on D.C. railways. On the Danish State Rys., for example, rail joints are fitted with welded fish-plates and the double-track line rails are connected about every 300 m. (984′) by transverse connections. We are informed that the loss on the contact line is 30 %, and that by the rails 5 % of the energy supplied to the contact line. When bonds are not used, they are replaced to some extent by transverse connections connecting the two rails ; they are used by the German and Hungarian Railways and follow one another every 100 to 250 m. (328′ to 820′). In addi-

tion on all the railways with the exception of *Denmark* and *Austria,* the rails of double track are connected together; this precaution is only used on the *Austrian Federal Rys.* at level crossings. The distances apart the cross connections are provided by the different Administrations vary widely. This distance on the *Czechoslovak* and *Hungarian* Railways is about 200 and 1 000 m. (656′ and 3 280′) respectively; on the *Polish State Rys.* it is as much as 2 000 m. (6 560′). In stations, owing to the trains stopping and to shunting operations, the return currents through the rails not only arise more frequently but are stronger owing to the greater power developed during starting. For this reason the track in stations on the *Hungarian State Rys.,* for example, is fitted every 500 m. (1 640′) with cross connections. On the *Austrian Federal Rys.* the rule is that at the two ends of the station as well as in line with the signal box towards the middle of the stations, the shunting loops as well as the dead-end sidings shall be connected to the next track by cross connections. So that the running rails shall not be above earth potential they are connected to earth plates at level crossings, and particularly in stations; this arrangement is only found on a large scale on the *Deutsche Reichsbahn.* On railway sections in which the return current travels under very unfavourable conditions earthing plates and wires are not sufficient, but in addition special conductors, either underground or overhead, are used. The above shows that even though many of the Railways have had years of practical experience, it is not yet possible to formulate any definite conclusions on return currents and the use of rail bonds. The Swedish State Rys. like the *Union of Swedish Private Rys.,* usually employ for the return current an overhead conductor above the track, parallel to the contact line, and subdivided into sections some 5 km. (3.1 miles) in length which in their turn are connected electrically with the running rails. To these sections of the return conductor are connected the secondary windings of boosting transformers, whilst the current of the contact line is forced to pass through the different primary windings. The boosting transformers are built like current transformers with the same number of windings and the same wattless currents and losses in the iron. The main advantage of these arrangements is that they prevent disturbances of the adjacent telephone and telegraph circuits, so that for the latter less complicated and cheaper safety measures are sufficient. Nonetheless, the use of boosting transformers is limited to a small number of Railways.

Power losses in the contact lines are generally estimated, in the absence of suitable meters on electric locomotives; they are 3 to 6 % of the quantity of energy supplied to the contact line. The figures given differ considerably; the Swedish *Göteborg-Boras-Alvesta Ry.* estimates that these losses can be as high as 30 %. Their value depends upon the area of each feeder area, as well as upon the conditions of the line and the timetables, and therefore, ignoring the effect of variations in the weight of the trains, and the section of the contact conductor, are practically invariable.

The scheme drawn up by the *Rumanian Rys.* on a single-line railway of about 75 km. (46.4 miles), provides a double-wire contact line and an auxiliary positive conductor. The intention is to use steel suspension cables only in the stations; elsewhere all the conductors will be copper. To prevent unnecessary losses, the contact lines between the substations will be fed bilaterally.

5. Locomotives and motor coaches.

Whereas the railways have chiefly re-

duced the weight of recent types of locomotives by a wide use of welding, and also by using light metals, this does not apply to the electric locomotives of the *Hungarian* and *Czechoslovak* State Rys. It is noticed in a general way that in the case of motor vehicles of light construction, the reduction in current consumption becomes the more necessary the larger the weight borne by the carrying wheels. These wheels carrying the dead weight are necessary at high speeds if smooth running is to be obtained. Locomotives for moderate speeds need not have carrying wheels, so that the total weight becomes available for adhesion. Consequently on locomotives without carrying wheels the weight saved owing to light construction can be more usefully employed in increasing the power of the motors.

A very remarkable fact is that the *Swedish* and *Norwegian* State Rys. use a single type of locomotive with rod drive. In 1927 the *Deutsche Reichsbahn* gave up rod drive for individual axle drive, which will be used exclusively by the *Austrian Federal Rys.* on their new locomotives. The reason for this change of system lies in the many advantages of individual drive, the broad lines of which we will indicate later on. The chief advantage, which we will mention first of all, is that compared with rod drive, the weight per kilowatt of equipment installed, when related to the hourly rating is reduced from 30 to 50 %. Consequently locomotives with rod drive can be replaced either by more powerful locomotives with individual axle drive or by lighter locomotives of equal power. Besides, for constructional reasons, increases in the power of locomotive make it necessary to distribute the tractive effort over several motors which transmit their torque to the driving axles through gear wheels. The path of the energy flux is simple and sources of defect are as rare as possible, since the number of bearings and journals is reduced to a minimum with this type of drive, whatever the type of the traction motor. On a locomotive with rod drive certain important parts are subjected to forces varying continually in amount and direction. The result is vibration which causes heavy wear of all the motive parts of the motor, and also in the wheel flanges and rails, which is not the case with the individual axle drive, owing to its more uniform torque. In addition lighter motors have the advantage of being easier to handle in the shops. Individual axle drive has sometimes been criticised for not using the adhesive weight as well as rod drive, especially when there are three or more than three pairs of coupled wheels. Investigations made on this point show that this opinion is not quite correct, and today by using equalisers it is possible, particularly when starting, to obtain the most favourable conditions of adhesion. On locomotives with individual drive, the driving axles are not connected together when running round curves and can place themselves radially, at least to some extent. Consequently curve resistance is much lower with these locomotives than those with coupled wheels. A fact of great importance from the economic point of view is that the maintenance costs of locomotives with individual drive are much lower, both as regards running repairs and general overhaul.
This fact has been reported by the *Reichsbahn* and the *Austrian Federal Rys.* The savings obtained are the higher, the higher the power and speed of the locomotives.

According to the information received from the Railways consulted, the speed of the motors does not exceed 1 450 r.p.m. for the fastest locomotive at the hourly rating. The gear ratio has not been given except by the *Reichsbahn* and the *Austrian Rys.;* excessive reductions having been found unsatisfactory, it lies between 1 : 2.794 and 1 : 6.143. In

order to reduce the current peaks and prevent the wheels slipping when approaching the limit of adhesion, the greatest possible number of driving positions are provided. This condition is fulfilled excellently by the controller with fine regulation, which has the advantage of a more regular current pick up and a shorter starting period. This controller is used in a standardised form on some types of locomotives of the *Reichsbahn.*

Two of this Railways' locomotives, designed for a speed of 180 km. (111.6 miles) an hour, are fitted with a casing which is fairly streamlined; but as a rule all that is done is to round off the head.

The proportion of the adhesive weight used to produce the tractive effort has not been given except by the *Reichsbahn* and *Austrian Federal Rys.;* this value varies at the hourly rating between the limits 18.1 to 30 % of the adhesive weight.

On the *Hungarian State Rys.* locomotives with single-phase converters and three-phase asynchronous motors, are in service and can maintain speeds intermediate between the running notches of the traction motor for a certain period, so that the same locomotives can be used to haul express trains and goods trains.

The advantage of this system of traction is that 50-cycle industrial current can be used. The single-phase load of the track is divided as equally as possible between the three phases of the transmission line. The reactions of the unequally loaded phases on the general three-phase system are hardly perceptible. A further advantage of this system is the automatic regulation of the power factor, the result of which is to compensate the voltage drop in the contact line.

So far no locomotives have been built fitted with frequency converters. A possible application would be to feed three-phase traction motors from a single-phase contact line; however, rotary phase-converters as on the Hungarian locomotives are also used.

The carrying and driving axles of the locomotives of all the railways covered by the present report are fitted with axle boxes; the traction motors and auxiliary motors are generally equipped with roller bearings, except those on the *Polish* locomotives, which have brasses. Wheels of the electric motor coaches and their trailers are fitted with roller bearings. In *Austria,* however, brasses are preferred, and this is also the case in Germany with certain types of motor coaches. In the near future the brasses will be definitely replaced by roller bearings, not only on the electric locomotives but also on all classes of stock. The proportion of the tractive effort to the adhesive weight is, at the hourly rating, from 9 to 13 % on the *German* motor coaches, and from 9 to 11 % on the *Austrian* motor coaches. The other railways did not give any information on this point.

The *Danish State Rys.* on their recently electrified suburban lines only work trains of electric motor coaches of light construction. Each train is equipped with four motors coupled in series for starting, then in series-parallel, each pair of motors remaining in series. The speed is 1 050 r.p.m., hourly rating; the axles revolve in ball bearings and are gear driven, the ratio being 1 : 3,5

On all the Railways consulted, passenger coaches are fitted with electric resistance heating; steam heating by means of electric boilers carried in the motor vehicles is provided for on a fairly large scale in the electrification scheme of the *Rumanian State Rys.* The boilers will be carried on the electric locomotives so that the heating equipment extant in the carriages can still be used without alteration. This direct heating of the carriages has not been used so far, except on the transitional service over the electrified suburban

lines of the city of Warsaw. Tests of electric heating by steam and air are being carried out on the *Reichsbahn*. As the electrified system will be extended beyond the large centres of traffic towards the stations where the trains split up, a large part of the rolling stock will no longer pass over the steam operated lines, so that the steam heating equipment in the carriages will become useless. On the other hand, new carriages being built in the meantime will have to be fitted with a double heating. It should be mentioned to the credit of steam heating from the locomotive that it is not necessary to install special heating equipment, since that which exists already can continue to be used. In general the replies received from the railways show that the heating equipment of the carriages, except in the case of the Danish motor coaches, are not taken out of circuit, either by hand nor automatically, during the starting period, in order to reduce the heavy current consumption during the acceleration period. On the *Swedish State Rys.*, if necessary heating current can be saved by intermittently cutting off the heating of the train during the peak traffic period between the 20 and 25th December. In order to prevent increasing power consumption when climbing gradients, the heating can be cut off completely on short gradients; this is done in *Austria* on the St. Pölten- Mariazell-Gusswerk line. Automatic regulation of the temperature is only found in some of the more recent German coaches. On the Warsaw suburban lines, train heating regulation is semi automatic; the heating units are arranged on two separate circuits, one of which is fitted with automatic thermo-electric regulation, and the other is regulated manually. The extended use of automatic temperature regulation depends in part on knowing if the speed will be so increased that the windows of the carriages can no longer be opened by the passengers, as in this case the automatic regulation of the temperature will be part of the automatic control of the composition and renewal of the air, i.e. the vehicles will be air-conditioned, and the problem will then be usefully solved along with that of air conditioning. The average annual consumption of energy varies between 4 and 10 % of the total power used. The upper limit, 10 %, is reported by the *Swedish State Rys.*

On railways owning locomotives or motor coaches with regenerative braking, the installation of special equipment in the substations has not been necessary, but the vehicles had to be fitted with it. The additional weight is for example 1.5 tons on the *German* motor coaches and about 5 tons on the *Norwegian* locomotives. The *German* motor coaches are provided with resistance braking equipment and regenerative braking equipment, as well as an auxiliary compressed air brake. The regeneration is about 16 % of the braking energy for a power factor of 1. The *Norwegian* locomotives recover up to 45 % of the total load of the train with a power factor lying between 0.8 and 1.

For uniform running speed on down gradients, and equal train weight, the down gradient alone decides the use or not of regenerative braking. The flattest gradient on which regenerative braking can be usefully employed is estimated by the Hungarian State Railways as 1 in 250; no other information was received on this subject. For uniform speed and equal train weight, the value of the energy regenerated depends on the gradient; when slowing down, it it also dependent on the reduction in speed. Regenerative braking can be done either completely, i.e. without the assistance of mechanical brakes, or partly, by bringing into action the electrical of mechanical brake. This latter combination is applied, as we already mentioned, on some *German* electric coaches, as well as on *Norwe-*

gian and *Hungarian* locomotives. The *Hungarian Rys.* own a locomotive with a converter for complete regenerative braking, which can re-convert up to 70 % of the braking energy into electrical energy. A definite improvement of the power factor in the contact network by regenerating current can only be counted on under special line conditions, and with a dense traffic; the value attributed to this factor varies between 0.8 and 1.

The trials the *Reichsbahn* is carrying out on the Höllental and Dreiseen line should be noted. This line, with gradients 1 in 18, is 56 km. (35 miles) long and is equipped for a line voltage of 20 kV., 50-cycles. The Titisee substation with Scott type connections takes from two separate phases the energy required for traction from the general distribution network as 110-kV. three-phase, each phase feeding half a section of line by corresponding auxiliary conductors. Four different types of locomotives with $B'_0\ B'_0$ wheel arrangement were ordered for this line as a trial. The first had series motors at 50 cycles, which is a prototype in this respect. The second, with eight nose-suspended motors which drive in pairs the four motor axles through gears, namely four three-phase synchronous motors and four single-phase motors with intermediate rotors excited by direct current. The driving wheels are driven, according to the arrangement, by individual action or combined action of the double motors, so that it is possible to get three main combinations and consequently three standard speed steps. With the first speed the two motors of each axle are grouped in cascade; there is a limit of stability at which this coupling can be used, but this is beyond what can apply in practice on the railways. With the second speed the single-phase motors work alone, and the three phase-induction motors are running light. Owing to the intermediate rotors, the single-phase motors act as if they had perfect revolving fields. Single-phase motors compensated in this way are little affected by voltage fluctuations and do not get out of step, even after rather serious voltage drops; they have practically no limit of stability. When running on the third step, the three-phase current induction motors fed by single-phase machines act in this case as phase-converters and work by themselves.

For starting and passing through the speed steps as well as for braking, water resistances are used so that all the coupling operations take place without sparking. The passage through the different steps is made without any interruption of the tractive effort. If when running down a gradient and retuning to the lower speed notches, the traction motors are driven hypersynchronously relatively to the running steps corresponding to their working, they become current generators and regenerative braking takes place automatically.

In addition, two locomotives are equipped with rectifiers, with and without polarised grids. On the locomotive with rectifiers fitted with polarised grids, the motor voltage is regulated by the voltage of the rectifier transformer and by the grid. Unlike the locomotive with rectifiers without polarised grids, this locomotive can be used to regenerate power. With the exception of the locomotive with rectifiers without polarised grids, all the locomotives in question lend themselves to regenerative braking and resistance braking. The tests of the locomotives for the Höllental line have not yet been completed.

The above-mentioned locomotive with converters of the *Austrian Rys.*, of the 1'E1' type only exists in a single example; it merits perhaps a more detailed description on account of its particular method of construction and working. An important and new feature of this locomotive is a rotary converter

which converts direct current into single-phase current taken from the transformer after an intermediate conversion into polyphase current. The energy is thus transformed twice. The group of machines is composed of a synchronous phase converter and two frequency converters coupled together on a common shaft. The two frequency converters are coupled on the commutator side in series with the rotor of the traction motors and coupled electrically and mechanically by a shaft to the phase converter. This machine divides the single-phase current into symmetrical polyphase current which is then rectified into direct current by the frequency converters. The voltage of the direct current can be adjusted. The stators of the frequency converters can be put out of gear and made to revolve in the opposite direction; by this means the power factor of the phase converters can be maintained at unity on the single-phase side, in spite of variations in the power. By fixing a given initial position of the stators and thereafter giving them a rotary displacement, it is possible to send wattless power into the contact line, so that the power factor can be regulated. The set of machines is adjusted to the speed of synchronism by an A.C. series motor. The direct current is taken from the principal brushes on the commutator of the frequency converters to the series coupled rotors of the traction motors, the excitation of which is independently assured by the starting motor working during the normal running as a direct-current generator. In addition there is a shunt excitation fed by frequency converters, which is used at the end of regenerative braking. In the traction motors the field of the stator and the current in the rotor are independent and constantly adjustable. Consequently the starting torque can be adapted exactly to circumstances; it is 21 500 kgr. (47 400 lb.). The continuous power is about 1 600 h.p. for a continuous tractive effort of 11 100 kgr. (24 470 lb.); the maximum speed is 60 km. (37.3 miles) an hour.

V. — Final remark.

Question VI expounded above covers almost the whole electric traction field with the sole exception of the problems in connection with generating stations. Therefore, we have been obliged to condense our report and in particular to limit ourselves to examining only part of the replies to the questionnaire; we have only been able to discuss at greater length the questions especially dealing with the reduction of the consumption of energy. We end our report with sincere thanks for the trouble taken by the various Railways in answering the questionnaire.

(See overleaf detailed questionnaire and replies.)

Detailed ques

I. ALTERNTING-CURRENT RAILWAYS.	*German State Railways.* (Bavaria-Wurtemberg System.) (Höllental line).	*Austrian Federal Railways.* (*A*) Lines west of Salzburg. (*B*) Salzkammergut line : Attnang-heim-Stainach-Irdning. (*C*) Gross-Schwechat-frontier section the Vienna-Pressburg line. (*D*) St. Pölten-Mariazell-Gusswerk line.
1. General.		
1. *Length of electrified lines, in km.* . . . (a) *single track* . . . . . (b) *double-track* . . . . . (c) *with more than 2 tracks.*	(*a*) 267.55 km. (*b*) 880.39 km. (*c*) 16.41 km. Höllental line : (*a*) 56 km.	*Lines* (*A* to *D*) at the end of 1935 : (*a*) (*b*) 313, of which 91.3 km. is the s track 2' 6" gauge (maximum gradie 1 in 37) Mariazell line.
2. *Type of electrical traction (nominal voltage, frequency.*	Single - phase 15 kV., 16 2/3 cycles. Höllental line : single-phase 20 kV., 50 cycles.	Single-phase, 15-kV. at contact line, 1 cycles on the lines (*A* to *C*). For line (*D*), single-phase 6 500 V., 25 c
3. *Annual consumption of energy measured at the supply point for the last working year :* (a) *kWh.* . . . . . (b) *voltage*	260 974 661 kWh. 110 kV. 5 426 022 kWh. 15 kV.	*Line* (*A*) : 134 159 000 and 117 584 000 on the 55-kV. and 15-kV. side. *Line* (*B*) : 7 307 684 on the 15-kV. side. *Line* (*C*) : 1 762 315 kWh. on the 15-kV. *Line* (*D*) : 3 088 547 kWh. on the 6 500 V
4. *Point at which the energy used is supplied (power house, substation, converting station or feed point of the contact line).*	260 974 661 kWh. at the power house. 5 426 022 kWh. at the power house and feed point of the contact line.	*Line* (*A*) : 134 159 000 kWh. at the house and 117 584 000 kWh. at the station. *Line* (*B*) : 7 307 684 kWh. at the house. *Line* (*C*) : 1 762 315 kWh. at the power h *Line* (*D*) : 3 088 547 kWh. at the direct point and at the substation.
5. *Load factor (ratio of maximum to average load during 8 760 hours per year) :* (a) *at the power house* . . . . . (b) *in the substations :* *up to 50 000 kWh. per week* . . . . *from 50 000 to 200 000 kWh. per week.* *from 200 000 to 500 000 kWh. per week.* *over 500 000 kWh. per week.* . . .	(*a*) 2.3 at power house. (*b*) 3.9 from 200 000 to 500 000 kWh., and 2.6 for more than 500 000 kWh.	*Line* (*A*) : In the power houses, the ca tion of the load factor is difficult, to the lack of measuring instruments. summation of the load diagrams of th power stations has given 1.8 to 2.3 w maximum of about 2.4. The factors substations show greater variations; also lack in measuring apparatus. Substations : with 50 to 200 MWh. per 5.8 to 13.7 ; over 200 MWh. per week to 8.0.
6. *Average power factor (cos φ) at the power house or the point of supply.*	Cos φ = 0.70.	*Line* (*A*) : Capacity factor estimated for of kVAh. recorders ; we calculate the annual power factor as being 0.7 in tion to the supply side of the substa

e and replies.

Royal ungarian State ailways.	*Norwegian State Railways.*	*Sweden : State Railways. Göteborg-Boras-Alfvesta Co.*	*Turkish State Railways.* Projected electrification : Catalagzi-Eregli (on the Black Sea).	*Jugoslav State Railways.* (Electrification under consideration.
190 km.	Length of lines (including those under construction) in round figures : (*a*) 250 km. ; (*b*) 50 km. ; (*c*) 7 (3-track).	(*a*) 2.148 km. (*b*) 448 km. (*a*) 70 km.	(*a*) About 54 km.	Narrow gauge : 760 mm. (*a*) 240.8 km.
igle-phase, 16 kV., 0 cycles.	Single-phase, on an average 15 kV., 16 2/3 cycles.	Single-phase 16 kV. and 15, 16 2/3 cycles. Single-phase 16 kV., 16 2/3 cycles.	Single-phase 16 kV.. 16 2/3 cycles.	Under consideration : D. C., 3 000 V. (1 500 V.) or single-phase 15 kV., 16 2/3 cycles.
Mio (*) h., 16 kV.	(*a*) 32.5 Mio. (*) kWh. for the existing lines in service, of about 192 km. length. (*b*) Average 15 kV.	(*a*) In 1935 : 56 Mio. (*) kWh. for the mineral Railway ; 290 Mio. kWh. for the lines south of Ange. (*b*) 4 000-V. single-phase current ; 6 300-V. three-phase current. (*a*) Cannot be given. (*b*) 16 kV.	(*a*) Initial traffic : 9.23 Mio. (*) kWh. ; Future traffic : 20.3 Mio. kWh. (*b*) Voltage of the transmission line not yet decided.	...
stations, on low-tension e.	Single - phase current, partly supplied by the railway power stations, 80 kV. or 55 kV. respectively, transformed to 15 kV., and partly as three-phase current from the general distribution network. This is transformed in the motor-generator stations of the railway.	For the mineral railway, by the Porjus power house. For the lines south of Ange, by the converter substations. From the converter substations.	Will be received at the Kozlu substation.	...
Estimated factor, 5 for 000 kWh. er week.	(*a*) at the power house, about 3.75. (*b*) substations transmitting more than 200 000 kWh. per week. Load factor 5/4.	Loading for the mineral line about 2 800 hours ; for the lines south of Ange, total loading 4 540 hours. For the individual stations, 2 050 to 3 320 hours. Energy consumption in the substations : 11.8 to 49.1 Mio. kWh. each year. For the mineral railway : In 1929, 105. Mio. kWh. were delivered for a period of 3 850 hours under load. In the year 1929, 0.96 to 18.13 Mio. kWh. were consumed in the various substations. In the year 1935, however, 0.78 to 7.6 Mio. kWh. were consumed.	(*b*) Supply side of the Kozlu substation ; for the greatest initial traffic (50 000 to 200 000 kWh.), 9.5 ; for maximum traffic (20 000 to 500 000 kWh.), 4.13.	...
φ = 1 to 5, inductive.	Measurements of the power factor, not carried out in such a way that results could be published. In some of the three-phase substations automatic regulation of the power factor.	The power factor is regulated.	Value estimated at 0.90 where power received at substation.	...

Note : Mio. = millions ($\times 10^6$).

I. ALTERNATING CURRENT RAILWAYS.	*German State Railways.* (Bavaria-Wurtemberg System). (Höllental line).	*Austrian Federal Railways.* (*A*) Lines west of Salzburg. (*B*) Salzkammergut line : Attnang-heim-Stainach-Irdning. (*C*) Gross-Schwechat-frontier section the Vienna-Pressburg line. (*D*) St. Pölten-Mariazell-Gusswerk line.
7. *In preparing the train timetables, do you take into account the available power supply, especially the load conditions of the supply companies, with a view to using any surplus energy in the power house at certain hours of the day and night, or in order to reduce the losses?*	No.	No.
B. Transmission lines.		
1. *Method of distributing the energy : independent or joint (traction current and industrial current); kind of current : voltage; frequency.*	Independent, only for traction. Single-phase current, 110 kV., 16 2/3 cycles.	*Line* (*A*): Energy distribution indepen from industrial current; single-phase rent, 55 kV. on the average. *Line* (*D*): Energy supplied direct from power station and two substations. current is transmitted at 27 kV.
2. *Approximate length of the transmission lines in km. :* (a) *with independent energy distribution.* (b) *with joint energy distribution.* . . .	Independent 662 km.	*Line* (*A*): about 490 km. *Line* (*D*): about 80 km.
3. *State for last year the :* (a) *maximum power supplied for traction, kW.* . . . . . (b) *maximum power supplied for other purposes, kW.* . . . . . (c) *energy consumption for traction, kWh.* (d) *energy consumption for other purposes, kWh.*	*a*) About 70 000. *c*) 260 974 661.	*Line* (*A*): (*a*) 46 000; for (*b*) not determ for want of measuring instruments. *Line* (*B*): (*a*) 6 800. *Line* (*D*): (*a*) 2 400.
4. *What are the measured or estimated losses in the transmission lines :* (a) *in kWh?* . . . . . (b) *as a percentage of the energy transmitted?*	Estimated 10 000 000 or 4 %.	*Line* (*A*): 6.5 to 10 % of the yearly su from the power house; the upper applies to the years when the water ditions were bad and large quantitie energy had to be transmitted to hus the water supplies.
5. *What is the maximum voltage drop in the transmission lines, excluding special cases?*	About 8 % on the longest transmission line.	*Line* (*A*): The losses are measured from power house and the busbars of the stations. Highest value, 20 % of the tial voltage. Part of the losses are b ced by super-compounding.

Royal Hungarian ıte Railways.	*Norwegian State Railways.*	*Sweden : State Railways. Göteborg-Boras-Alfvesta Co.*	*Turkish State Railways.* Projected : Catalagzi-Eregli (on the Black Sea)	*Jugoslav State Railways.* (Electrification under consideration).
timetables are out to suit affic requi-ıents.	No special arrangement.	The amount of energy required is calculated in advance and the suppliers advised prior to the beginning of the new year's contract.	No.	...
transmission does not be-g to the rail-y but is a part the general tribution net-rk. Joint dis-ıution, three-ıase current, kV., 50 cycles.	The single-phase transmission is used almost exclusively for traction purposes, whereas the three-phase is used for industrial purposes as well. Single-phase voltage : 80 kV. and 55 kV. respectively, 16 2/3 cycles. The three-phase voltage varies with the installation ; 50 cycles.	For the mineral railway : transmission line for single-phase current, 80 kV. 15 cycles. For the lines south of Ange : general transmission network for three-phase current, 50 to 220 kV., 50 cycles. Joint : three-phase current, 50 kV., 50 cycles.	The transmission line is used for traction as well as for light and power. Three-phase current, probably between 30 and 100 kV., 50 cycles.	With direct current : three-phase transmission lines 60 kV., 50 cycles. With single-phase current : single-phase transmission line, 60 kV., 16 2/3 cycles.
...	(*a*) Single-phase line about 115 km. (*b*) Three-phase line usually for joint distribution.	For the mineral railway, 500 km. For the section south of Ange, 2 000 km. 100 km. for the joint energy distribution.	(*b*) Three - phase, line about 25 km.	...
...	The energy used for traction and heating is given in A/3. The other consumptions are variable and amounted in the last working year to about 5 000 000 kWh.	(*a*) For the mineral railway, 20 100 kW. used, 30 000 kW. available. For the sections south of Ange : maximum load in the year 1935, 62 400 kW. Cannot be given for traction.	(*b*) Calculated at about 10 000 kW. (*c*) With the initial traffic, 9.23 Mio. kWh. ; for future traffic, 20.3 Mio. kWh.	...
...	For the Hakavik-Asker-Skollenberg transmission line : (*a*) About 800 000. (*b*) About 5 %.	... Cannot be given.	Unknown as yet.	...
...	Voltage drop about 7 % (balanced by compounding at Hakavik).	...	...	...

I. ALTERNATING CURRENT RAILWAYS.	*German State Railways.* (Bavaria-Wurtemberg System) (Höllental line).	*Austrian Federal Railways.* (A) Lines west of Salzburg. (B) Salzkammergut line : Attnang-Puchhei nach-Irdning. (C) Gross-Schwechat-frontier section of the Pressburg line. (D) St. Pölten-Mariazell-Gusswerk line.
6. *What steps have been taken to reduce transmission losses :* (a) *by controlling the distribution of the load between the generating stations feeding the traction system in parallel?* (b) *by interconnecting the transmission lines?*	...	*Line (A)*: — (*a*) It is proposed to install a measurement station; the central control loo the load conditions of the 5 generating s Distant-measurement of the total useful pow wattless energy and also of the voltage at t bars. *b*) In case of growing demands the existing lines will be duplicated by a 110-kV. line. vement in the operating conditions betwe 5 power stations.
(c) *by automatic voltage regulation at various points of the system; at what points?* (d) *by controlling the distribution of wattless current between the generating stations feeding the traction system in parallel?*	(*d*) As far as possible.	*Line (A)*: — (*c*) Voltage regulators are fitte automatic wattless current anticompoundin equipment, as the supply of magnetising increases, diminishes the value of the volta greatly decreases fluctuations of the wattless (*d*) The distribution of the wattless energy controlled when the distant-recording sta completed. *Line (D)*: — (*c*) Automatic voltage regulation power station, and transformers in the feed to raise the voltage when the current increases.
(e) *by the use of synchronous machines or of condensers; at what places?* (f) *by introducing choking coils in the transmission lines between two power stations*	...	*Line (A)*: — (*e*) During the summer the Sp plant is used as phase-shifters (to husband th supplies). A group of machines installed quently acts as the existing machines, as phase displacement, for a triple output of current. (*f*) In order to improve the efficiency of a lin 120 km. long, choking coils with a react 4×10 ohms are inserted between the Sp station and the Ruetz station at about the of the line. The transmission losses and the tions in the voltage and the wattless load ha reduced as a result.
(g) *by cutting out the largest possible number of transformers or rotary converters under no load or lightly loaded?* (h) *by other measures?*	(*g*) Yes.	*Line (A)*: Number of machines in the power stations adjusted to the load, but with reserve, to meet unforeseen loads. Distan ring equipment will enable the loading co and units in service to be supervised. Tw provided in the substations with one as res heavy loads. No regulations as regards the putting in and out of service.
7. *What steps have you taken as regards the insulators in order to reduce discharge losses?*	...	*Line (A)*: Discharge losses are small. In th design, no flange on the caps.
8. *What steps have you taken to reduce losses due to corona effect?*	...	*Line (A)*: No corona loss at 55 kV.

Royal Hungarian State Railways.	*Norwegian State Railways.*	*Sweden : State Railways. Göteborg-Boras-Alfvesta Co.*	*Turkisch State Railways.* Projected : Catalagzi-Eregli (on the Black Sea).	*Jugoslav State Railways.* (Electrification under consideration).
...	(*a*) One power station supplies the peak load and another the normal power. When the hydro-electric power stations work in parallel (Ofoten Railways), the loads are distributed by means of the turbine governors. Where a hydro-electric power station works in parallel with a converter station, motor generators are used (at Alnabru and Svelgfoss).	... By the use of synchronous motor converters with an angle of phase lead of 0.7, a constant voltage is expected.	...	...
...	(*c*) The voltage is not regulated in the transmission lines ; compounding in the power station is all that is used. (*d*) The wattless current is distributed to some extent between the power stations, by automatic devices.	... ...	Probably by maintaining constant voltage at the substation incoming line.	...
...	(*e*) Synchronous motors or condensers are not used. (*f*) Is not used.	... ...	...	...
...	(*g*) Only the number of sets required to meet peak loads is used. (*h*) No other measures prescribed.	... ...	(*g*) A converter will be cut out at small load.	...
...	...	...	Stronger insulation prescribed on account of the proximity of the sea.	...
...	...	...	...	...

I. ALTERNATING CURRENT RAILWAYS.	*German State Railways.* (Bavaria-Wurtemberg System). (Höllental line).	*Austrian Federal Railways.* (A) Lines west of Salzburg. (B) Salzkammergut line : Attnang heim-Stainach-Irdning. (C) Gross-Schwechat-frontier sectio the Vienna-Pressburg line. (D) St. Pölten-Mariazell-Gusswerk line
C. **Substations.** 1. *Number of substations of the same kind and what kind?*	8 substations worked by hand. 1 substation controlled from a distance.	*Line (A)*: 13 substations (4 in buildin 9 plants partly in open air), desig the same principles. *Line (D)*: 2 substations (roofed in). arrangement.
2. *Equipment of the substations of similar kind (manual, distant, or automatic control), number of units, as well as their power at the hourly rating (the half-hourly rating for converter sets). momentary, and continuous power.*	9 substations with 22 transformers. Total capacity of: 162 000 kVA. for 1 hour. 214 000 kVA. for 3 minutes. 140 000 kVA. continuously.	*Line (A)*: 55-kV. switches in the substati tant controlled from the distribution 15-kV. switch hand operated. 12 sub each with 3 voltage transformers and o two voltage transformers. Continuous capacity: 2 400 to 3 840 kVA. t corresponds an overload capacity of 4 7 for 10 min. and 7 600 kVA. for 1 min., 6 000 kVA. for 10 min., and 9 000 kVA. fo respectively. *Line (D)*: Manual control only. There is former per substation for a continuous 000 kVA.: step-down ratio: 27 kV. to 25 cycles.
3. *Is the number of machines and apparatus in service in substations adjusted to the actual load conditions by switching units in and out, in order to reduce the losses?*	Yes.	*Lines (A) to (D)*: The number of transf in use varies with the load conditi
4. *Is the adjustment made soon after the load alteration, in all cases automatically, or after longer intervals of time?*	The transformers are switched in or out by hand in the substations, to suit the load.	*Line (A)*: Transformers are switched out according to the instructions load distribution office.
5. *Transformer efficiency :* a) *at full-load and when cos φ = 1.* . . b) *at half-load and when cos φ = 1.* . .	(a) 97.8 %. (b) 98.2 %.	*Line (A)*: Efficiency of transformer o dard power of 2.4 MVA. at 1/2, 1 load: old types, 98.2, 97.7, 95.1 recent types, 98.7, 98.2, 96 %. Th lues are all with cos φ = 0.8.
6. *Efficiency of the converter sets :* a) *at full-load and when cos φ = 1.* . . b) *at half-load and when cos φ = 1.* . .	...	...
7. *Do the converter sets converting the three-phase current from the supply to single-phase current at another frequency directly produce the single-phase current at the line voltage, so avoiding losses due to double voltage transformation?*	...	...
8. *Do you use grid controlled mutators for converting three-phase current into single-phase? State their efficiency.*	...	...
9. *When regeneration is used, what additional measures are taken and equipment provided for this purpose in the substations?*	None, there being little regeneration when braking railcars.	...

Royal Hungarian State Railways.	*Norwegian State Railways.*	*Sweden : State Railways. Göteborg-Boras-Alfvesta Co.*	*Turkish State Railways.* Projected electrification : Catalagzi-Eregli (on the Black Sea).	*Jugoslav State Railways.* (Electrification under consideration).
4 similar ıbstations.	In service : 4 transformer substations and 3 converter substations.	For the mineral railway : 13 transformer substations. For the lines south of Ange : 15 converter substations. 1 substation.	1 substation (three-phase current into single-phase with asynchronous motors and synchronous generators), perhaps travelling converters.	...
ally operated ; n with two ısformers of kVA. conti- power, and kVA. over- for ten mi- .	In the transformer substations, voltage transformers of 2 500 to 1 500 kVA. with a total capacity of 18 000 kVA. Total power of converter substations, 5 500 kW.	4 substations, each with three 1 100-kVA. transformers. 9 substations each with two 1 500-kVA. transformers. 15 converter substations (1 to 4 converters) for an individual normal loading of 2 400 up to a maximum of 6 000-kVA. 1 motor-generator of 2 400-kVA. continuous capacity and 5 000-kVA. momentary capacity.	3 motor generators (1 reserve) each of 3 000 kVA. continuous capacity, 6 000 kVA. for 10 minutes, the latter at most once hourly.	For D. C. : Rectifiers and transformers. For single-phase current, only transformers.
ding to the each substa- has 1 or 2 sformers in	See statement under B/6.	Adjustment is being provided.	Since there is only 1 substation, for reasons of safety in working, at least two units are in service, with the third unit in reserve. There is therefore no need for any graduation.	...
cases, mostly long enough vals.	See statement under B/6.	22 mobile converters (on wheels).	...	...
98.8 %. 98.75 %.	(*a*) for 2 500 kW. = 98.5 %. for 1 500 kW. = 98.0 %. (*b*) for 1 250 kW. = 98.7 %. for 750 kW. = 98.0 %.	For the mineral railway : (*a*) 0.984 new type, and 0.964 old type. (*b*) 0.985 new type, and 0.962 old type. The annual efficiency of the 4-kV. transmission between the generators in the Porjus power station to the 16-kV. plant of the transformer substations was : 0.792 % in 1935, and 0.837 % in 1929. (*a*) 0.985.	Not decided, normal.	...
...	In the Alnabru substation : (*a*) for 3 000 kW. = 87.5 %.	Annual efficiency : 0.832. (*a*) 0.88. (*b*) 0.86. ...	Not decided, but will be normal. ...	...
...	Single-phase transformers between the alternators and the contact line.	... 3-kV. to 6-kV. transformers.	Small power alternators for 15 000 V. at terminals have not been provided for in the scheme ; hence it will be necessary to transform from 3 kV. to 15 kV.	...
...	We have no mutators.	Not used up to now. No.	No.	...
ecial plant in sformer sub- ons.	No additional plant.	No.	...	Regeneration is being considered ; considerable current saving could be obtained.

I. ALTERNATING CURRENT RAILWAYS.	*German State Railways.* (Bavaria-Wurtemberg System). (Höllental line).	*Austrian Federal Railways.* (*A*) Lines west of Salzburg. (*B*) Salzkammergut line : Attnang heim-Stainach-Irdning. (*C*) Gross-Schwechat-frontier secti the Vienna-Pressburg line. (*D*) St. Pölten-Mariazell-Gusswerk lin
D. Contact lines.		
1. *System used (overhead contact line or third rail)?*	Overhead line.	Overhead line.
2. *In the case of an overhead line, what is the total or equivalent cross sectional area of the copper in the different conductors, expressed as a percentage of the length of lines electrified. Is the contact line reinforced by auxiliary conductors and if so, what is the total or equivalent section of copper of these auxiliary conductors on the different sections, expressed as a percentage of the lengh of the electrified lines.*	75 % of the contact line 100 mm² copper, 25 % with 80 mm² copper. The area of the copper in the carrying cable is equivalent to 25 mm². On sections fed at one end only, the contact line is reinforced by auxiliary conductors of an area of 75 mm². In length, these conductors are about 25 % of the total length of the contact lines.	*Lines (A)* to *(C)* : Contact lines about 1 on 9 % of the length, 100 mm² o of the length (on short sections in tunnels, with carrying cables of the equivalent cross section is abou greater) ; about 80 mm² on 16 % length. Auxiliary conductors of 5 on 38 % of all lines ; 70 mm² on 12 100 mm² on 9 % of all lines. *Line (D)* : Equivalent cross section of line ; 86 mm² ; Feeder, 70 mm² ; T sion line, 2 × 50 mm² ; all copper.
3. *On multi-track lines, are the conductors in parallel, in order to reduce the losses.*	No.	*Line (A)* : Conductors not in parallel o track lines ; provision has been m arranging them in parallel, if needed *Lines (B)* to *(D)* : No, since they are track.
4. *Are the sections of contact line between two substations usually fed at both ends to reduce the losses, or is each half fed separately, and for what reasons?*	The sections of the line are normally fed at both ends through coupling switches.	Usually the contact lines are fed fr end if possible.
5. *Are special precautions taken to improve the return of the current through the running rails, through the earth, or through the rails and the earth :*		
(a) *are special rails bonds used, and how are they fastened?*	(*a*) No bonds ; cross connections every 100 to 200 m., attached with clips.	*Lines (A)* to *(D)* : — (*a*) The old lin fitted with longitudinal and tra bonds. New lines without bonds. F with bolts or wedges.
(b) *are parallel running roads connected to each other, and at what distances apart?*	(*b*) Cross connection of the tracks every 500 m.	(*b*) At level crossings and at both stations, cross bonds, as also from board platform across all the track
(c) *are auxiliary conductors used and of what kind?*	(*c*) Exceptional cases : with bad underground water conditions, overhead conductors as return conductors.	(*c*) On metal bridges with guard rail insulated rail joints, auxiliary con
(d) *are earth plates used to improve the earth return and at what distances apart?*	(*d*) Earthing plates at stations and level crossings.	(*d*) On old lines, earth plates in pl about 1.8 km. apart.
6. *What are the approximate losses in the contact line, expressed as a percentage of the amount of energy delivered by the substations.*	Estimated at 3 %.	*Lines (A)* to *(D)* : For want of meters locomotives, no particulars as rega losses are available ; average loss es at about 6 % of the energy transm the pantographs.

Royal Hungarian State Railways.	*Norwegian State Railways.*	*Sweden : State Railways. Göteborg-Boras-Alfvesta Co.*	*Turkish State Railways.* Projected electrification : Catalagzi-Eregli (on the Black Sea).	*Jugoslav State Railways.* (Electrification under consideration).
Overhead line.	Overhead line only.	Overhead line.	Overhead line.	Overhead contact line.
Running roads, 100 mm² copper. Sidings, 65 mm² copper. No auxiliary conductors.	Usually the sectional area of contact wire is 80 mm² and of carrying wire 50 mm² both copper. On certain lines, feeders 100 and 50 mm², of copper.	The contact line consists of two copper conductors of a total cross sectional area of 130 mm². 130 mm² cross sectional area.	Copper contact line, 100 mm² ; carrying cable, 35/mm² bronze (Austrian standard design). Auxiliary conductors 2 × 70 mm² copper.	...
enever possible, arranged in parallel.	For safety, each track is equipped independently.	The contact lines are not arranged in parallel on double-track lines. No.	...	...
e each substation belongs a different phase of the ree-phase supply system, eas fed by the substations e separated by phase limits. ed at one end only.	Transformer and converter substations only work in parallel when necessary.	Separate contact lines between the substations ; feed at one end.	...	...
No longitudinal rail bonds. Rails are cross-bonded every 0 m., tracks in the open ery 1 000 m., and in sta- No auxiliary conductors. ns every 500 m. Earth plates only in sub- tions.	(*a*) In general, welded bonds. (*b*) Every 200 m. (*c*) and (*d*) No.	(*c*) Copper return conductors of 130 mm² and booster transformers to prevent disturbance in lines with weak current. (*d*) No earthing plates. (*c*) Through a return conductor with booster transformers about 5 km. apart.	(*a*) Usual rail bonds. (*b*) and (*c*) No. (*d*) Not decided.	...
Loss in contact lines approximately 2 to 3 %.	This question was not studied closely.	Maximum 30 %.	Probably about 8 %.	...

I. ALTERNATING CURRENT RAILWAYS.	*German State Railways.* (Bavaria-Wurtemberg system.) (Höllental line).	*Austrian Federal Railways.* (A) Lines west of Salzburg. (B) Salzkammergut line : Attnang heim-Stainach-Irdning. (C) Gross-Schwechat-frontier secti the Vienna-Pressburg line. (D) St. Pölten-Mariazell-Gusswerk line
E. Locomotives, motor coaches and other rolling stock.		
1. *What steps have been taken on recent locomotives to reduce the current consumption?* (a) *reduction of the tare weight, and methods adopted?* (b) *number of r.p.m. of the motors, at the hourly rating?*	*(a)* Extensive use of welded construction. As far as needed, use of light metals (ventilation ducts, etc.). (b) E 18: 1450 r.p.m. / 112 km./h. E 44: 1430 r.p.m. / 73 km./h. E 04: 1110 r.p.m. / 98 km./h.	*Lines (A) and (B) — (a)* Sheets o alloy for the outside panelling a tails of the apparatus (such as c ler casing). Welded locomotive bod mes, casings and bosses of tractio auxiliary motors. *(b)* Number of r.p.m. of the tractio tor, average 60 % of the maximu volutions; in the case of the 40 standard motor 840 r.p.m. armatu 690 mm. diameter. *Line (D) — (b)* 700 r.p.m.
(c) *rod, individual or combined axle drive?* (d) *gear ratio.*	*(c)* Individual drive alone. *(d)* E 18: 2.794:1 / 150 km./h. E 44: 4.61:1 / 90 km./h. E 04: 3.41:1 / 120 km./h. for V max.	*Lines (A) and (B) — (c)* Originall drive; now only individual axle *Line (C)* . Rod drive. *Line (D)* : Rod drive. *Lines (A) and (B) — (d)* Gear 1:6.143 to 1:3.313. No attempt beyond 1:5. *Line (D)* : Gear ratio 1:3.
(e) *fine regulation to avoid current surges when starting, and to make better use of the adhesive weight. What proportion of the adhesive weight is used?* (f) *streamlining?*	*(e)* By fine regulation only according to the standard method of the Reichsbahn. E 18 E 44 E 04: 26.2 % 26.5 % 30 % = tractive effort : adhesive weight. *(f)* E 18 — 140 km./h. and E 19 — 180 km./h.	*Lines (A) and (B) — (e)* No fine lation; the number of steps as hi possible, up to 21 (Loco. R 128 cluding 2 reserve steps for re voltage. Proportion or adhesive w used 1:5.5, at the hourly rating. *(f)* The locomotives are not strean as a whole but the ends are strean *Line (D) — (e)* No fine regulation, 8
2. *If you have tried mutators mounted on locomotives or motor trains, what results were obtained?*	...	*Line (A)* : No locomotive with mut A transformer locomotive with D.C. synchronous converter set. starting tractive efforts, little te to wheel slip, full regenerative br automatic maintenance of speed slight variations according to the dients. Considerable increase in w as compared with locomotives wit gle-phase motors.
3. *What steps have been taken to reduce current consumption on the latest motor coaches?* (a) *methods of reducing the dead weight?* (b) *number of r.p.m. of motors, hourly rating?*	Light type, light metals, and welded construction. el T 1900: 1395 r.p.m. el T 1998-99: 1650 r.p.m.	*Lines (A) and (B)* : Welded bogie, and frame, welded construction of tion and auxiliary motors (for la armature winding). Number of r.p the traction motors about 60 % o maximum r.p.m.; standard 200-kW tor, 1128 r.p.m with an armatur meter of 490 mm. *Line (D)* : No motor coaches.
(c) *rod, individual or combined axle drive.* (d) *gear ratio.*	Individual drive only. el T 1800: 2.81:1 / 120 km./h. el T 1900: 2.11:1 / 160 km./h. el T 1998-99: 3.41:1 / 120 km./h. V. max.	*Lines (A) and (B)* : Individual axl ve, nose suspended motors. No gea tio smaller than 1:5. For the A.C. ries ET10 and 11, ratio is A.C.l series ET10 and 11, ratio is 1:3. 1:3.39.

Royal Hungarian State Railways.	*Norwegian State Railways.*	*Sweden : State Railways. Göteborg-Boras-Alfvesta Co.*	*Turkish State Railways.* Projected electrification Catalagzi-Eregli (on the Black Sea.	*Jugoslav State Railways.* (Electrification under consideration.
No steps taken.	*(a)* In the case of the latest locomotives, reduced weight has been the main preoccupation.	...	*(a)* Locomotive frames and other parts welded. *(b)* Not decided.	...
		(a) No steps taken. *(b)* 1350 r.p.m.		
...	*(c)* Rod drive on all locomotives.	*(c)* Rod drive only (standard 80-ton-locomotives).	*(c)* Individual axle drive. *(d)* Not decided.	...
		(c) Rod drive.		
...	...	...	Fine regulation with an infinite number of steps. Adhesion factor at the maximum tractive effort — 1:3.25.	...
		(f) No streamlining.		
No mutators.	No trials with mutators.	...	...	...
No motor coaches.	*(a)* Latest motor coaches on inclines up to 1 in 22. Weight 35.5 t. 4 motors tramway suspension; bogie frame and body framing welded. Wood body and aluminium sheeting. Total weight includes the multiple-control gear. *(b)* Power 464 kW., hourly rating, at 32 km./h., 1160 r.p.m.	... *(b)* 4 × 400 reduced to 1350 r.p.m.	No motor coaches.	...
...	...	...	...	...

I. ALTERNATING CURRENT RAILWAYS.	*German State Railways.* (Bavaria-Wurtemberg system.) (Höllental line).	*Austrian Federal Railways.* (A) Lines west of Salzburg. (B) Salzkammergut line : Attnang-heim-Stainach-Irdning. (C) Gross-Schwechat-frontier sectio the Vienna-Pressburg line. (D) St. Pölten-Mariazell-Gusswerk line
(e) *fine regulation to avoid current surges when starting and to make better use of the adhesive weight. What proportion of the adhesive weight is used?* (f) *what classes are streamlined?.* .	Cam control with induction coils. el T 1800 el T 1900 el T 1998-99 19 % 14.8 % 13 % Express motor coaches for 160 km. per hour are streamlined.	*Lines (A) and (B) :* No fine regu With types ET10 and 11 the ad weight is used in the ratio 1:8 1:10.5 at the 1-hour rate. In the ET11 coaches, the ends are ed. and flush entrance doors fitt the sides.
4. *Are roller bearings used for the motors and on the axles of the locomotives, motor coaches, and carriages, or is their use under consideration.*	All the motors have roller bearings; no roller bearings on locomotive axles. A few motor coaches with roller bearings. « Peyinghaus » axle boxes most used.	*Lines (A) and (B) :* Roller bearin the traction and auxiliary motor dinary bearings for the axles c electric motor coaches.
5. *Are the trains electrically heated?* (a) *directly or by means of steam accumulators.* (b) *is the heating current cut out at starting to reduce the load?*	*(a)* In general, resistance heating. Coaches with electrical air heating and electrical steam production are in service experimentally. *(b)* No.	*Lines (A) to (D) — (a)* Trains d heated electrically; *(b)* Heated also during the starti riod. *(d)* Heating cut out when climbi gradients.
(c) *is the train heating regulated by the train staff exclusively?*	*(c)* No; also regulated by the passengers.	*Lines (A) and (B)* — Compartment ches available for the passengers t except in ET11 coaches wherein h attended to by the train guard.
(d) *is the electrical heating automatic?* (d) *what is the approximate energy consumption for heating the train in proportion to the total power consumption?*	*(d)* Automatically controlled on a small number of new carriages. *(e)* Yearly average : 5.22 %.	*Lines (A) to (D) — (d)* No auto regulation of the train heating. *(e)* Energy consumption for heatin recorded.
6. *If regenerative braking is used :* (a) *on what gradients is there regeneration?* (b) *is regenerative braking complete or only partial?* (c) *what is approximately the power recovered, as a percentage of the train braking work?*	*(a)* On the Höllental line (1 in 18 gradients), experimental locomotives are equipped with regenerative and resistance braking gear. No results available as yet. *(b)* Other lines : motor coaches with regenerative and resistance braking; no definite results. With electrical brakes, only partial braking, completed by the compressed air brakes. *(c)* Regeneration about 16 %.	*Line (A) — (a)* Regeneration only the converter-fitted locomotive of there is only one; down gradien steep as 1 in 31. *(b)* Complete braking. *(c)* About 70 %.
(d) *what is the weight of the additional apparatus required for regeneration, and the increase in the power of the motors?* (e) *what effect has the regeneration on the power factor in the A.C. plant?*	*(d)* Additional weight in the case of motor coaches about 1.5 t. *(e)* Regeneration occurs when cos $\varphi = 1$.	*Line (A) — (d)* No additional w due to regenerative braking. *(e)* Regeneration when cos $\varphi = 1$ ap mately. Regenerative braking with locomotive has no effect on the factor of the System.

Royal Hungarian State Railways.	*Norwegian State Railways.*	*Sweden : State Railways.* *Göteborg-Boras-Alfresta Co.*	*Turkish State Railways.* Projected electrification Catalagzi-Eregli (on the Black Sea.	*Jugoslav State Railways.* (Electrification under consideration.
...	...	...	...	...
No.	Roller bearings are used for the traction motors and axle bearings.	Where possible roller bearings are used to avoid hot boxes.	No, speeds small.	...
Trains directly heated lectrically. No.	*(a)* Direct electrical train heating. *(b)* No.	No. *(a)* Direct electrical heating. *(b)* According to circumstances, switched off during peak traffic (usually from 20 to 23 December). *(a)* Direct electrical heating. *(b)* No.	*(a)* Not decided.	*(a)* Electrical heating considered.
Electrical heating controlled by the train staff.	*(c)* No.	Heating controlled by the train staff. *(c)* Yes.	...	...
No automatic regulation. Energy consumption or train heating about %.	*(d)* No. *(e)* Is not separately measured.	*(e)* About 10 % of the total consumption. *(d)* No. *(e)* 5 % energy consumption.	...	...
The gradient on which egeneration begins varies with the weight and peed of the train, the urves and the atmospheic conditions. Experiene shows it is at least 1 n 250. Regeneration is only artial between the speed teps.	*(a)* Up to 1 in 58. *(b)* Partial. *(c)* About 45 % of the total gross load.	No regeneration. No regeneration.	...	...
With asynchronous traction motors, no additional paratus is necessary. Power factor, practilly not influenced by egeneration.	*(d)* In the case of a locomotive weighing 135 t., additional weight 5 t. The power of the motors was not increased. *(e)* Power factor with regeneration is from 0.8 to approximately 1.	...	...	...

II. DIRECT-CURRENT RAILWAYS.	*Austria :* Vienna-Gross-Schwechat section of the Vienna-Frontier line (near Hainburg).	*Danish State Railway* (Lines round Copenha
I. **General.**		
1. *Length of electrified lines, in km. :* (a) *single track* . . . . . (b) *double-track* . . . . . (c) *more than two tracks*	*(a)* 12.6.	*(b)* 17. *(c)* 13.
2. *Type of electric traction (nominal voltage).*	D.C., 600-V. on the Vienna-Gross-Schwechat section.	D.C., 1 500 V.
3. *Yearly energy consumption, measured at the supply point, during the past working year :* (a) *kWh.* . . . . . (b) *voltage.*	*(a)* 467 530 kWh. *(b)* 600 V.	*(a)* In the first working (1-6-1934 to 31-5-1935) Mio (*) kWh. *(b)* 10 000 V.
4. *Point at which the energy used is supplied (power station, substation, converting station, or feed point of the contact line).*	4 supply points.	Rectifier substations.
5. *Load factor (ratio of maximum to average load during 8 760 hours per year) :* (a) *at the power house* . . . . . (b) *in the substations :* *up to 50 000 kWh. per week.* . *from 50 000 to 200 000 kWh. per week.* *from 200 000 to 500 000 kWh. per week.* *more than 500 000 kWh. per week.*	...	Factor cannot be given. larly only the total e consumption of all su tions is known [see 3
6. *Average power factor (cos φ) at the power station or at the supply point.*	...	Power factor at the poi supply cannot be given
7. *In drawing up the train timetables, do you take into account the available power supply and in particular the load conditions of the suppliers with a view to using the surplus energy in the power house at certain hours of the day and night, or reducing the losses?*	No.	No.

Polish State Railways. (Warsaw suburban lines).	*Rumanian State Railways.* (Campina-Brasov trial line).	*Czechoslovak State Railways.* (Prague, Wilson Station with suburban lines).
100.	*(a)* 75.	*(a)* About 20. *(b)* About 5.
., 3 000 V.	D.C., 3 000-V.	D.C., 1 500 V.
No information, since the ıes are under construction.	*(a)* The calculated consumption for the high-tension side of the substation, about 30 Mio (*) kWh. *(b)* For feeding the substations 60 kV., 50 cycles.	*(a)* In 1935, 4 915 Mio (*) kWh. *(b)* 22 kV.
n rectifier substations.	High-tension side of the substations.	From the substation, primary.
Not yet ascertained.	...	*b)* 95 000 kWh. weekly; maximum power during quarter of an hour 1 820 kW. Average load for 8 760 hours : 560 kW.: ratio : 3.25:1.
er factor will not be below 2.	...	Not determined as yet.
xperience as yet.	...	No.

Note : Mio. = millions ($\times 10^6$).

II. DIRECT-CURRENT RAILWAYS.	*Austria :* Vienna-Gross-Schwechat section of the Vienna-Frontier line (near Hainburg).	*Danish State Rail* (Lines round Copen
B. **Transmission lines.**		
1. *Method of distributing the energy : independent or joint (traction and industrial current); kind of current; voltage and frequency.*	Line directly fed with current at line voltage.	All such questions ca be answered by th ply power house.
2. *Approximate length of the transmission lines, in km. :* (a) *with independent energy distribution* . . (b) *with joint distribution*	...	...
3. *For the last year, what was the :* (a) *maximum power supplied for traction, in kW.* (b) *maximum power supplied for other purposes, in kW.* . . . . . . (c) *energy consumption for traction, in kW.* (d) *energy consumption for other purposes, in kW.*	*(a)* For the Vienna-Gross-Schwechat-Frontier line, 2 000 kW. (D.C. and A.C.)	...
4. *What are the measured or estimated losses in the transmission lines :* (a) *in kW.* . . . . . . (b) *as a percentage of the transmitted energy?*	...	...
5. *What is the maximum voltage drop in the transmission lines, excluding special cases?*	...	...
6. *What steps have you taken to reduce the transmission losses :* (a) *by controlling the distribution of the load between the power houses feeding to the traction system in parallel?* (b) *by interconnecting the transmission system?*	...	All these questions c ly be answered b power station.
(c) *by automatic voltage regulation at different points of the system; at what points?* (d) *by controlling the distribution of wattless current between the power stations feeding the traction network in parallel?*	...	...
(e) *by the use of synchronous machines or condensers; at what places?* (f) *by inserting choking coils in the transmission lines between two power stations?*	...	...
(g) *by cutting out the largest possible number of transformers and converters under no load or lightly loaded?* (h) *by other measures?*	...	...
7. *What steps have you taken as regards the insulators, in order to reduce discharge losses?*	None.	...
8. *What steps have you taken to reduce losses due to corona effect?*	...	...

Polish State Railways. (Warsaw suburban lines).	*Rumanian State Railways.* (Campina-Brasov trial line).	*Czechoslovak State Railways.* (Prague, Wilson Station, with suburban lines).
ınsmission lines for joint listribution, three-phase, 35 :V, 50 cycles.	One third of the energy will be purchased; transmission lines remain the property of the energy suppliers. Joint distribution, three-phase 60 kV., 50 cycles.	Independent distribution, three-phase, 20 kV., 50 cycles.
Total length 300 km.	...	*(a)* A cable 3 km. long, of 3 × 50 mm² for 22 kV. from the power station to the substations.
Not yet obtained.	...	*(a)* Maximum in 1935 : 4 250 kW. *(c)* 4 915 Mio kWh.
4.5 % of the energy trans-ıitted .	...	Owing to the short length of the cable, losses are insignificant.
About 5 %.	10 %, attributed to the supplier.	...
ss section of the 35-kV. ne is so calculated that ıe loss be about 10 %. Not envisaged. Interconnection usued.	...	No steps taken to reduce transmission losses.
Not used. Not done in order to im-rove power factor.	...	...
No.	...	...
Not done. No.	...	...
l insulation.	...	...
ı 35 kV. and 70 mm² sec-ɔn, no loss.	...	...

II. DIRECT-CURRENT RAILWAYS.	*Austria :* Vienna-Gross-Schwechat section of the Vienne-Frontier line (near Hainburg).	*Danish State Railways.* (Lines round Copenhagen)
C. **Substations.**		
1. *Number of substations of the same kind, and what kind?*	2 substations not belonging to the railway as supply points.	3 substations with mercury vapor tifiers.
2. *Equipment of the substations of similar type (manual, distant, or automatic control), number of units as well as their power at the hourly rating (half hourly for converter sets), momentary, and continuous power.*	1 rectifier substation. 1 motor-generator substation.	Automatically-operated substatio the same principles : controll cally or from a distance. The control is from a switchbo the Enghave substation.
3. *Is the number of machines and apparatus in service in substations adjusted to the actual load by switching units in and out, in order to reduce the losses?*	No.	Yes.
4. *Is the adjustment made soon after the load alteration, in all cases automatically, or after longer intervals of time?*	...	Adjustments not very frequent, by relays. These can also be re by hand (local or distant contr
5. *Transformer efficiency :* (a) *at full-load and when cos* φ *1.* . . . . (b) *at half-load and when cos* $\varphi = 1$.	...	...
6. *Efficiency of converter sets :* (a) *at full-load and when cos* $\varphi = 1$. . . . . (b) *at half-load and when cos* $\varphi = 1$.	...	Continuous output of the rectifie 1 500 Amp. at 1 650 V. For a period of 40 seconds, 4 500
7. *Are rotary converters used for converting three-phase current into D.C., in order to reduce the losses?*	No.	No; rectifiers on account of their efficiency at all loads.

Polish State Railways. (Warsaw suburban lines).	*Rumanian State Railways.* (Campina-Brasov trial line).	*Czechoslovak State Railways.* (Prague, Wilson Station with suburban lines)
substations which rectify ne three-phase current.	4 substations with mercury vapour rectifiers projected.	1 substation with converters and mercury vapour rectifiers.
substations with distant ntrol. substation with manual ntrol. bstation completely auto-atic. ubstation with selective ntrol.	Automatic equipment : each substation has three 2 000-kW. D.C. units. 50 % overload for 2 hours, and 200 % for 5 minutes.	Manual operation. Rectifiers, 4 270 kW. continuous rating, capable of 15 % overload for 2 hours and 100 % for 1 minute; converter set 2 × 500 kW., and one converter group 2 × 1 000 kW. capable of 50 % overload for 2 hours and 100 % for 1 minute.
ber of units in use de-nds on the load.	Yes.	The rectifier is usually in service, and the converter sets in reserve.
in and out 2 to 4 times 24 hours.	Automatic.	...
96.6 %. 96.72 %.	...	2 × 500 kW. converter sets : 98.1 % full load, 97.8 % half load. 2 × 1 000 kW. converter sets : 98.4 % full load, 98.3 % half load. Rectifiers : 98.5 % full load.
onverters.	...	2 × 500 kW. converter sets, 95.6 % full load, 92.9 % half load. 2 × 1 000 kW. converter sets, 96.1 % full load, 93.4 % half load. Rectifier, 95.9 % full load, 96.1 % half load.
otary converters.	No.	...

II. DIRECT-CURRENT RAILWAYS.	*Austria :* Vienna-Gross-Schwechat section of the Vienne-Frontier line (near Hainburg).	*Danish State Railways.* (Lines round Copenhagen)
8. *Have rotary converters for transforming three-phase current into D.C. been replaced by mercury vapour rectifiers, with or without grid polarisation. If so, for what reasons?*	...	...
9. *In places where three-phase current is transformed into D.C. by mercury rectifiers, please state :* (a) *efficiency of the equipment;* (b) *measures taken to reduce the losses to a minimum?*	...	*(a)* Substations at Enghave and rup : 3 sets (including spar Flintholm : 2 sets (1 spare) ning of Holte on May 15th, 1 set (always 1 spare). *(b)* To reduce consumption of water, the water from the electric station is used for the vacuum pumps. The rec are cooled by circulating wate ed by means of refrigerators.
(c) *if inner or outer heating elements are used, what is the lowest temperature at which they work :* (1) *at full load . . . . . .* (2) *at short-period maximum load? . . .* (d) *under what circumstances do backfires occur?* (e) *are controlled grids used, and for what purpose?*	...	*(c)* Temperature of the cooling w between 40° and 50° C. *(d)* These circumstances are not k *(e)* For stabilising the rectifier neutralising backfires.
(f) *power factor at average and maximum load.* (g) *if difficulties have occurred on account of variations in the sinusoidal curve of the primary current, or on account of the saw-tooth shape of the secondary current curve, how have they been removed? If smoothing filters are inserted in the secondary circuit, for what reasons was this done?*	...	*(f)* The power factor is not know *(g)* We do not know of any cha the form of the primary cu Smoothing filters are inserted direct current circuit to preven turbances in the telephone line
10. *With regenerative braking, what additional measures and equipment have been adopted in the substations?*	No regeneration.	No regeneration during braking.

Polish State Railways. (Warsaw suburban lines).	*Rumanian State Railways.* (Campina-Brasov trial line).	*Czechoslovak State Railways.* (Prague, Wilson Station with suburban lines)
Not considered.	...	No.
For 5/4 load, 0.93; for /4 load 0.93; 3/4 load, 925; 2/4 and 1/4 load, 915 and 0.695 respectively. Cooling only under heavy ads; vacuum pumps not work when each recti- er is working indepen- ntly.	...	92 % for a load of about 50 % on the average.
Highest temperature of oling water 87° C. Recti- er output at full load : 000 to 2 500 kW., and for ort max. load periods, 3 nes as much. No experience as yet. For neutralising backfires.	...	*(d)* On three occasions, backfires with explo- sion of the oil circuit breaker. Cause : short-circuits near the substation. Backfires avoided by altering the anodes and using grids. Oil circuit breaker was strengthened and chocking coils inserted in the three- phase conductors. *(e)* No.
Smoothing filters provid-	...	*(f)* Estimated at 0.95.
No regeneration.	Regeneration projected. Excess regenerated energy will be ab- sorbed by resistances in the substations.	...

II. DIRECT-CURRENT RAILWAYS.	*Austria :* Vienna-Gross-Schwechat section of the Vienne-Frontier line (near Hainburg).	*Danish State Railways* (Lines round Copenhagen
D. **Contact lines.**		
1. *System used (overhead contact line or third rail).*	Overhead contact line.	Overhead contact line.
2. *What steps have you taken to reduce the electrical resistance of the 3rd rail?* (a) *use of special material in the conductor.* (b) *use of a special cross section* (c) *improvement of the rail bonds.*	...	...
3. *In the case of an overhead line, what is the total or equivalent copper cross sectional area of the conductors on the different sections of line, expressed as a percentage of the length of the electrified lines? Is the overhead line reinforced by auxiliary conductors. What is the total or equivalent copper cross sectional area of these auxiliary conductors on the different sections, expressed as a percentage of the length of the electrified lines?*	2 contact wires, each of 80 mm².	Total cross section (copper valent material) Contact line mm². Auxiliary conductors mm². 130 — 242 — 242 95 242 240 260 240
4. *Are the conductors on multi-track lines arranged in parallel, in order to reduce the losses?*	...	No.
5. *Are the sections of contact line between two substations usually fed at both ends to reduce the losses, or is each half fed separately, and for what reasons?*	...	At both ends to reduce losse
6. *What steps have you taken to reduce the electrical resistance of the 4th rail?* (a) *use of special conductive material?* (b) *use of a special cross section?* (c) *improvement of the rail bonds?*	...	...
7. *Have special steps been taken to improve the return of the current through the running rails, the earth or through both?* (a) *are special rail bonds used and how are they fastened?* (b) *are parallel running tracks connected to each other, and at what distances apart?*	*(a)* Longitudinal rail bonds. *(b)* cross bonds about every 100 m.	Bonds of large section : *(a)* bonds, 3 copper cables, cross sectional area : 180 secured by welding. *(b)* Yes, every 300 m.
(c) *are auxiliary conductors used, and of what type?* (d) *are earth plates used to facilitate the return of the current through the earth, and at what distances apart?*	...	No.
8. *What are the approximate losses in the contact line, expressed as a percentage of the energy supplied by the substations?*	...	Loss through contact line les 30 %. Loss through rails less than 5

Polish State Railways. (Warsaw suburban lines).	*Rumanian State Railways.* (Campina-Brasov trial line).	*Czechoslovak State Railways.* (Prague, Wilson Station with suburban lines).
Overhead contact line.	Catenary contact line.	Overhead contact line.
No third rail.	...	...
valent copper cross section the running roads (230 n.) : about 250 mm². On si-ngs (35 km.) : about 150 m².	Open roads : 2 contact wires each 100 mm², copper; 1 carrying cable 125 mm² copper; 1 positive reinforcing conductor 125 mm² copper on the Breaza-Darste section. Stations : Running track as above, but carrying cable of steel, 50 mm². Other tracks : steel carrying cable 50 mm² and 1 contact wire of copper, 80 mm².	All contact lines 200 mm². All carrying and reinforcing cables 160 mm², of copper.
uctors put in parallel by ange-over switches.	...	No.
act line sections fed at both ds.	Fed at both ends.	...
No 4th. rail.	...	..
rn of current by the rails. Welded longitudinal bonds copper, 100 mm². Distance between cross bonds. out 2 km.	..	*(a)* Welded copper bonds 35 mm². Resistance of 1 m. of bonds — 1 m. rail, about 0.00012 ohm. *(b)* Copper cable 95 mm², spaced 200 m.
auxiliary conductors ; no th plates.	*(d)* Yes.	*(d)* No.
out 10 % loss is expected.	...	..

II. DIRECT-CURRENT RAILWAYS.	*Austria :* Vienna-Gross-Schwechat section of the Vienna-Frontier line (near Hainburg).	*Danish State Railway* (Lines round Copenhag
E. Locomotives, rail motor coaches and other rolling stock.		
1. *What steps have been taken on the latest locomotives to reduce the current consumption :*		We have no locomoti
(a) *reduction of the tare weight and by what means?*	*(a)* No reduction.	
(b) *number of r.p.m. of the motors at the one hour power rating?*	*(b)* Between 560 and 620 revs. per min.	
(c) *rod, individual, or combined axle drive?* . .	*(c)* Individual drive (tramway type suspension).	...
(d) *gear ratio?*	*(d)* Between 1:4.5 and 1:5.0.	
(e) *fine regulation to prevent current surges when starting, and to make better use of the adhesive weight? What proportion of the adhesive weight is used?*	*(e)* No fine regulation. (12 and 14 running steps.)	...
(f) *streamlining?*		
2. *What has been done on the latest rail motor coaches to reduce the current consumption?*		
(a) *methods of reducing the dead weight?* . .	*(a)* Nothing.	*(a)* In the latest coac light alloy details are and welding.
(b) *number of r.p.m. of the motors at the hourly rating?*	*(b)* 600 r.p.m.	*(b)* Power at the hourly ing : 120 kW. at r.p.m.
(c) *rod, individual, or combined drive?* . . .	*(c)* Individual axle drive.	*(c)* Individual drive.
(d) *gear ratio?*	*(d)* 1:4.9.	*(d)* Gear ratio 17:59. S of the teeth hardened.
(e) *fine regulation to prevent current surges when starting, and to make better use of the adhesive weight.*	*(e)* No fine regulation	*(e)* When starting, the tors of a motor coac arranged in series and wards in pairs in pa (2 motors always in for a voltage of 1 500
(f) *streamlining, and for what classes?*	*(f)* No.	*(f)* No.

Polish State Railways. (Warsaw suburban lines).	*Rumanian State Railways.* (Campina-Brasov trial line).	*Czechoslovak State Railways.* (Prague, Wilson Station with suburban lines).
e suburban lines being under construction, no experience available.	...	*(a)* Weight reduction not specially considered.
...	...	*(c)* Most of the locomotives have individual axle drives.
...	...	...
answer to question 1.	...	...
...	...	...
...	...	...

II. DIRECT-CURRENT RAILWAYS.	*Austria :* Vienna-Gross-Schwechat section of the Vienna-Frontier line (near Hainburg).	*Danish State Railwa* (Lines round Copenha
3. *Are roller bearings used on the motors and on the axles of the locomotives, motor coaches and carriages, or are you proposing to use them?*	No roller bearings.	Roller bearings for mot mature shafts, and fo hicle axles.
4. *Are the trains electrically heated?* (a) *directly or by means of steam accumulators.* (b) *is the heating current cut off at starting to reduce the load?*	*(a)* 600-V. electric radiators. *(b)* No.	*(a)* Yes : of 1 500-V heaters in series. *(b)* Heating current cu automatically during ing period.
(c) *is the train heating regulated solely by the train staff exclusively?*	*(c)* By the train staff only.	*(c)* By the train staff.
(d) *is the electrical heating automatic?*. . . .	*(d)* No.	*(d)* No.
(e) *what is the approximate energy consumption for heating the train, in proportion to the total power consumption?*	*(e)* During the heating period, about 23 %.	*(e)* Unknown.
5. *If regenerative braking is used :* (a) *on what gradients is there regeneration?*. . (b) *is regenerative braking complete or only partial?* (c) *What is approximately the power recovered, as a percentage of the train braking work.*	*(a)* None.	No regeneration.
(d) *what is the weight of the additional apparatus required for regeneration and what is the increase in the power of the motors?* (e) *what effect has the regeneration on the power factor in the A.C. plants?*	...	...

Polish State Railways. (Warsaw suburban lines).	*Rumanian State Railways.* (Campina-Brasov trial line).	*Czechoslovak State Railways.* (Prague, Wilson Station with suburban lines).
rasses for traction motors and axle-boxes of locomotives; SKF roller bearings for traction motors and axle-boxes of motor coaches.	...	The motors of the locomotives are fitted with roller bearings.
) Suburban trains with electrical radiators, each of 700 W., each 4 in series, 3 000 V. Through steam trains on the 8 km. transit line electrically heated from electrically-heated steam boiler.) Heating current is not switched off.	*(a)* By means of a steam accumulator; space is provided on the locomotive for carrying the heating apparatus.	...
) Regulation of heating by the passengers not provided for.) Radiators in two circuits : the first thermo-electrically controlled; the second by the train staff.) No information hereon.	...	...
No regeneration.	...	...
...	...	...

[625. 611 & 656. 27]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

13th SESSION (PARIS, 1937).

QUESTION XIII.

Specifications for the fixed plant of railways with light traffic, intended to prevent the use of unnecessarily expensive track equipment, and generally to give economical working.

REPORT

(Continental Europe and Colonies, Egypt),

by A. SVOBODA,

Engineer, Technical Adviser, Czechoslovak Ministry of Railways.

Foreword.

In view of the different results arrived at when the same questions are dealt with by a number of reporters, we agreed the questionnaire for Question XIII with M. Van Noorbeck, Chief Engineer, Permanent Way Department, of the Belgian National Light Railways Company, who is the Reporter on this question for the other countries.

A joint questionnaire, in our opinion, has the advantage of dealing with the problem from the same point of view, a useful and desirable procedure.

The questionnaire was divided into 60 main questions and was sent to 140 Railway Administrations. To avoid possible misunderstandings we had included in the joint questionnaire some explanatory notes. One of these notes dealt with the interpretation of *fixed plant* and the other the definition of *railways with light traffic.*

According to these notes, by the description *fixed plant* was meant all equipment other than the locomotives and rolling stock, i. e. everything affecting capital expenditure, maintenance costs and operating costs. In the light of this definition, the questionnaire was divided into parts covering the construction of the lines, superstructure as well as substructure, layout and equipment of passenger and goods stations (including buildings), signalling and safety equipment, and telegraph and telephone equipment.

The idea of *lines with light traffic,* briefly explained at the head of the questionnaire was further made clear in order to dispel any doubtful interpretation by the Railways concerned. We pointed out in the questionnaire that it chiefly applied to lines of local interest (light railways, branch lines, secondary railways, colonial railways) open to public passenger and/or goods traffic, but

which serve a more restricted area than the usual light railway and on which the speeds are lower irrespective of the type of traction used. To make the description clearer, i.e. to avoid any misunderstanding and make it easier to examine the data, we asked the Administrations to give precise definitions of the descriptions of *railways with light traffic,* such as *local railways, district railways, departmental (provincial) railways, secondary lines, colonial railways,* etc. We also asked the railways whether, in their opinion, the description *railway with light traffic* ought not to apply to other kinds of railways (except urban railways, purely tourist railways, and funicular railways) such as *forest railways* in so far as such railways are opened to a limited public traffic.

The questionnaire in addition asked if and when the Railway Administrations used the description — *railway with light traffic* — (except as regards the higher classes of railways) or that of *railways with lighter traffic.* They were also asked to what classes of railway these names should be applied, and what were the limiting conditions for the respective definitions (train speeds, track gauge, axle loads of the engines and other rolling stock, etc.).

We raised these questions purposely, seeing that in Central Europe the description of *railways with light traffic* also includes little used lines of the main-line Systems.

Only one Railway answered this special question and recommended that the criterion of a *railway with little traffic* be the speed of the trains which it suggested be 60 km. (37.3 m.) an hour as a maximum.

In our opinion, in view of a more precise definition of *lines with light traffic,* which in Germany are called *Nebenbahnen* the first factor to be considered should be the speed, and then the track gauge, the type of permanent way, the axle loads, and the equipment of the lines, all much simpler than on the main lines, should be taken into account.

This opinion seems to be confirmed by certain actual cases. For example, a colonial railway operated on lines similar to those resorted to on main lines, the maximum speed being 100 km. (62 miles) an hour, cannot be classed amongst railways which, in the current phraseology, also include local lines, light railways, etc.

Certain Administrations even advised us that they could not supply any information, as they did not work any lines falling into the class of lines with light traffic; after the misundertanding was cleared up, they sent in the required data.

* * *

CHAPTER I.

Generalities and lengths of lines with light traffic.

Out of 140 railways consulted, working 296 563 km. (184 279 miles) of lines, a general answer was received from 82 (58 %), and of this number 36 (25.7 %) answered the questionnaire. Only three administrations replied to all the questions.

* * *

In our opinion, railways with light traffic can be divided conveniently according to their equipment into the two following groups :

a) Continental lines connected with main lines;

(*b*) lines not connected with main lines (lines of different gauge, and colonial lines).

This being so, we will now analyse the fixed plant of railways with light traffic. To this end we have drawn up a synoptical table in which the information received has been summarised and classified according to the various track gauges (p. 763/9).

* * *

The 36 Railways (*) who answered the questionnaire work a total of 198 424.56 km. (123 297.4 miles) of lines, 71 612.34 km. (44 498.6 miles) of which represent lines with light traffic, i.e. 36.09 % of the total.

175 763.3 km. (109 216.2 miles) of the total belong to 22 European railways working 61 723.95 km. (38 354.2 miles) or 35.11 % of lines carrying light traffic. In the non-European countries 14 Railways operate 22 661.256 km. (14 081.3 miles) of which 9 888.39 km. (6 144.5 miles) or 43.63 % are light-traffic lines.

* * *

CHAPTER II.

Construction of the lines.

Included in the light-traffic lines 2 600 km. (1 615.6 miles) of lines are not laid on railway-owned land, and of this length 600 km. (373 miles), or about 1 %, are laid along the public roads.

* * *

As shown in the synoptical table, 11 different gauges are in use on the light-traffic lines. The various gauges were given by the replying Railways, but some of them differ little in practice [e.g. gauges of 1 435 mm., 1 440 mm. and 1 445 mm. (4′ 8 1/2″, 4′ 8 23/32″ and 4′ 8 7/8″)].

As regards the total number of railways, that in the second column of the table is not the same as the number of railways who replied to the questionnaire. This is due to the fact that certain Administrations operate light-traffic lines of different gauges : for example, one European railway operates 4 lines of 4 different gauges, so that this railway appears in column 2 several times, i.e. for each of the respective gauges.

Most of the railways recommend the standard gauge for economic reasons, in order to avoid transhipment of goods. A few railways prefer the metre gauge and a small number recommend the 760-mm. (2′ 6″) and 600-mm. (1′ 11 5/8″), local circumstances being evidently taken into account.

In our opinion the existence of one or several connecting points of the light traffic railways with the main-line railway or another railway is the important factor to be taken into account.

The table gives the *steepest-gradient conditions*. On most of the railways this is 1 in 50 to 1 in 33. One Administration recommends even steeper gradients in order to avoid excessive construction costs whereas several favour easier gradients, and the remainder maintain the point of view that the best solution should be based on calculations.

We are inclined to agree with this latter view, as the operating costs, which are recurrent in nature, should be taken as the main factor on which the decision should be based, with a view to obtaining an economical service.

* * *

CHAPTER III.

Lay-out and running speeds.

In connection with this question, notably as regards the minimum radius of curves in the open road and the shortest

(*) We received replies from five Administrations after our report was sent in. They could not be included in the report.

length of straight between reverse curves or curves in the same direction, the replies sent in were interesting, though not uniform.

The table gives information in the case of each track gauge. We have refrained from showing particulars for each individual railway so as to make the table as simple as possible.

The replies show that some railways use a straight section between curves, even when transition curves are used. The result of experiments on high-speed lines show, however, that the straight can be ommitted when the curves have transitions. Transition curves are not used on 4 000 km. (2 500 miles) of light traffic lines, covered by this report.

The *running speeds* (see table) differ and vary between 20 and 100 km. (12.4 and 62 miles) an hour.

Railways using different methods of traction allow their railcars to run at speeds higher by 20 % than in the case of ordinary motive power.

It cannot be said that the speed generally mainly depends on the section of the rails and the axle loads alone. One railway with 46 kgr./m. (92.7 lb. per yard) rails and a 17.5-ton engine axle load allows a speed of 100 km. (62 miles) an hour, whereas another with 42.8-kgr./m. (86.3 lb. per yard) rails and a maximum axle load of 17 tons only authorises a maximum speed of 50 km. (31 miles) an hour. This shows that the maximum speed, apart from safety, is governed by many factors such as the sleeper spacing, the size of ballast, the layout and the gradients.

The synoptical table gives data relating to all railways and some data in respect of one particular railway, as regards the maximum speed relatively to the weight of rails used, the sleeper spacing, the dimensions of the ballasting, and the maximum axle load.

* * *

CHAPTER IV.

The track.

Data on the design of the track and in particular of the weight of the rails in relation to the dimensions of the sleepers, the sleeper spacing, the dimensions of the ballast, and the engine axle loads are given in the table, and provide the basis for useful comparisons.

The weight of the rail per linear metre, varies between 12 and 52 kgr., i.e. between 24.2 and 104.8 lb. per yard, nearly all the railways using Vignole (flat-bottomed rails).

36 railways use on 52 lines with 11 different gauges 41 sections of rail, the weights of which are as follows :

12, 13.75, 14.25, 15, 15.8, 16, 18, 18.25, 19, 20, 20.84, 21.6, 22, 22.12, 22.3, 23, 23.6, 24, 24.4, 25, 26, 26.15, 27.62, 29.3, 30 31.1, 31.15, 32, 33.4, 34.5, 35.65, 36, 37, 40, 41, 42.8, 44.35, 46, 49, 50, 51, and 52 kgr./m., i.e. 24.2, 27.7, 28.7, 30.2, 31.8, 32.2, 36.3, 36.8, 38.3, 40.3, 42.0, 43.5, 44.3, 44.6, 45.0, 46.4, 47.6, 48.4, 49.2, 50.4, 52.4, 52.7, 55.7, 59.1, 62.5, 60.7, 62.8, 64.5, 67.3, 69.5, 71.9, 72.6, 74.6, 80.6, 82.6, 86.3, 89.4, 92.7, 98.8, 100.8, 102.8 and 104.8 lb. per yard.

As regards the type of *rail joint* — except in a few cases — the suspended or overhanging joint is used, the supported joint being used by one Railway only.

Except for one Railway on which the joints are staggered, all the Railways use opposite joints.

Most of the Railways use angle fish-plates; some use flat fish-plates and a few both types.

Nine Railways are welding the rails. The table gives the lengths of rails welded together. Question II of the Agenda of the Paris (1937) Congress dealing specially with the various welding processes, information in connection with this matter are omitted here.

Light-traffic Railways

SYNOPTICAL TABLE

Track gauge, *in millim.*	Number of Railway Systems.	Length in km. of all lines of respective railways (total).	Length in km. of light-traffic lines in Europe.	Length in km. of light-traffic lines in other countries safe Europe.	Length in km. of light-traffic lines total.	% of all light-traffic lines.	% of all lines.	Max. gradient *s = steam loc. e = elect. loc.*	Width of formation, *metres.*	Minimum radius of curves in open road, *metres (t = transition).*	Straight section, *in metres,* between curves reverse.	Straight section, *in metres,* between curves same direction.	Weight of rails used. *kgr./m.* Number of sections.	Rail welding. Max. lengths welded together, *metres.*	Materials used in the track (*).	Sleepers Dimensions, *in m.*	Sleepers Spacing, *in m.*	Dimensions of ballast layer, *metres.* b.s. = *broken stone,* g = *gravel,* sa. = *sand,* sl. = *slag.*	Max. axle loads of motive power. *metr. tons.*	Max. running speed, *km./h.*	Method of traction. *s = steam e = elect. r = rail-car.*	Point signals. d.l. = *double light.*	Are signals installed? (*yes* or *no* in certain cases).	Telegraph and telephone. *tg = telegr. tf = teleph.*	Level crossings. Lowering barriers. *a.s. = automat. signals.*	Recommendations : *rc = rail-cars. mb = motorbuses.*	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
600	2	26 738	600 (**)	96	696	0.981	0.35	1 in 25	2.6-3.0	40*t*	10	10	12.0 12.0	...	s (*) r	1.2×0.2×0.1 1.3×0.2×0.11	0.53-0.7 0.7	1.5×0.15, sa.	6.5 6.5	20-35 20	s rc	d.l.	in c.c.	tf	b	rc	(*) s = standard. r = reused (recovered when renewing elsewhere). (**) Approximate data.
750	4	30 438	600 (**)	1 592.4	2 192.4	3.07	1.104	1 in 25	2.5	75*t*	10	10	15.0-18.0 (4) 16.0	...	s r	1.4×0.2×0.1	0.69-0.78 0.78	2.3×0.25, g	6-6.5 6.5	40 30	s rc	d.l.	in c.c. junction stations.	tg tf	b	rc	...
760	5	64 216	3 757.4	...	3 757.4	5.25	1.89	46	3.2	40*t*	10	10	13.75-44.35 (7) 14.25, 22.12	24-56	r s	1.5×0.2×0.14	0.66-0.9 0.66	2×0.25, g	6 6	40 40	s rc e	d.l.	in c.c. ...	tg tf tf	b	(***)	(***) No information asked.
785	1	22 154	600 (**)	...	600 (**)	0.847	0.326	40	2.9	75*t*	10	10	...	...	r	1.5×0.2×0.1	...	0.13-0.2, sa.	...	40	s rc	d.l.	Yes.	tf	b	rc	...
1 000	19	73 547	9 307.65	5 767.99	15 075.64	21.065	7.59	90*e* 55*s*	2.15-4.70	40*t*	10	10	14.25-36.0 (19) 25.0, 30.0	24-800	r s	1.8×0.22×0.18 2.0×0.18×0.12	0.8-1.33 0.82	2.5×0.25, g	7.5-14.0 10.8	25-70 70	s rc e	in c.c.	d.l. junction stations.	tg, tf, wireless.	b s	Simplicity of motorbus services for pass-traffic.	...
1 050	1	580	...	146	146	0.213	0.075	30	4.0	100	55	...	27.62	...	s	...	...	2.2×0.15, sl.	12.62	35	s	leading-in points.	in c.c.	tf	b	Standard track. rc	...
1 067	2	3 905	113	400	513	0.726	0.258	17	4.00-4.15	100(*t*)	...	20	20.0-33.4 (4) 23.0-33.4	...	s	2.0×0.2×0.1	0.68-0.86 0.68	2.5×0.4, g ...	7.0-15.0 15.0	60 60	s	...	in c.c.	tg tf	b	...	...
1 100	1	119	119	...	119	0.176	0.059	30	2.10	300	30	30	18.0, 24.0 (2)	Yes.	s	1.8×0.18×0.22	0.67	g	7.0	42	s rc e	leading-in points.	Yes.	tf	...	...	...
1 435	11	123 647	45 677.7	434	46 111.7	64.31	23.23	46	4.0-4.8	75*t*	...	...	20.0-52.0 (15) 20.0, 34.5, 30.0	24-72	r s	2.4×0.2×0.15 2.6×0.28×0.14 2.7×0.25×0.16	0.69-0.81 0.69-0.9	0.2. p 3.5×0.3, bs.	10.5-16.4 16.4-13.25	45-75 60 60-85	s rc e	leading-in points.	in c.c.	tf tg wireless	b s	rc	...
Two : 1 000 / 1 440	1	3 688	45	...	45	0.062	0.022	20	...	80*t*	40	40	...	...	...	...	...	3.5×0.35, g	...	...	...	Yes.	...	tf	...	...	...
1 440	3	4 751	904.2	...	904.2	1.27	0.455	55	5.0	80*t* (40) *t*	40	40	20.0-30.0 (4) 30.0	800	s	2.6×0.22×0.13	0.8-0.9 0.85	3.2×0.5, sa.	16 15	60-80 75	s rc	d.l.	Yes.	tf	b s	...	...
1 445	2	2 532	...	1 452	1 452	2.03	0.731	15	5.5-6.0	300*t*	100	100	25.0-46.0 (3) 46.0	...	s	2.3×0.22×0.14 2.5×0.24×0.12	0.68-0.73 0.73	3.27×0.35, bs.	15-17.9 17.9	100	s rc e	in c.c.	Yes.	tf	b	rc s dispatching.	...
...	...	...	61 723.95	9 888.39	71 612.34	100	36.09	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

The dimensions of the sleepers on which the rails are carried are given in the table. The sleepers are made of wood, iron, mild steel and reinforced concrete.

The wood sleepers are made of : oak, untreated and treated, i.e. creosoted and carbonised superficially, treated and untreated pine, treated beech and larch, and untreated teak. In the majority of cases treated oak (on 16 railways) and steel (on 13 railways) are used. Three Railways are using reinforced concrete sleepers and report good results.

As a rule the rails are laid on bearing plates. On 17 Railways, however, they are fastened to the sleepers directly, i.e. without interposition of bearing plates. The latter fastening method is used on 17 000 km. (10 560 miles) of lines (24 %), 11 000 km. (6 835 miles) of which are in Europe.

The *ballast* is 0.15 to 0.50 m. (6″ to 20″) thick. This layer is made up of 0.25 to 0.40 m. (10″ to 16″) of gravel, and above it 0.20 to 0.35 m. (8″ to 14″) of broken stone; although in many cases 0.15 to 0.50 m. (6″ to 20″) of sand is used. On a smaller scale, cinders (0.25 m. = 10″), sand mixed with small gravel (0.35 m. = 14″), stone chippings (0.35 m. = 14″), hard limestone (0.15 m. = 6″), blast furnace slag (0.35 m. = 14″), river gravel (0.35 to 0.50 m. = 14″ to 20″), sea and quarry sand (0.15 m. = 6″) mixed with earth, are used. This proves that the materials available near the line are used for ballast.

It is unusual for two *lines to cross on the level* but when such crossings exist, they are made of standard section rails.

The design of points is governed mainly by the gauge; the crossing angle is from 4° 50″ to 8° 36′ 47″. The switch blades are usually straight; curved blades are used in a few cases only.

The length of the blades depends to some extent on the gauge and varies between 2.50 and 9 m. (8′ 2 1/2″ to 29′ 6 3/8″). Straight blades are 2.50 to 5 m. (8′ 2 1/2″ to 16′ 5″) long, and are used on both standard and narrow-gauge lines.

Curved blades 3.20 to 9 m. (10′ 6″ to 27′ 5 1/8″) long are used in switches on curves, when there is insufficient space.

The *crossings* are either built up from rails, or castings, usually of manganese steel.

Point indicators (signals) are used at the points on light traffic railways during daylight only (disc signal). The only lighted point signals are those giving access to junction stations.

Point signals are not used on 20 065 km. (12 470 miles) of line, i.e. about 25 % of the light-traffic lines, 11 679 km. (7 257 miles) of which or about 16.2 %, are in Europe. Only on 2 437 km. (1 514 miles) of line are point signals, i.e. day-time disc signals used.

On 22 755 km. (14 080 m.) of line point signals are only used at switches not protected by ordinary signals. The data in connection with the point signals are given in the table.

The automatic control of the points by the trains, when taken trailing, has been introduced on 3 railways of 750-mm.-760-mm. (2′ 5 1/2″ and 2′ 5 7/8″), and standard gauges.

The layout of such a point operating device (fig. 1) on narrow-gauge lines is very simple.

A cylindrical threaded rod, fastened at one end to the stock rail and guided at the other end by an angle section fixed on the middle of the sleeper, carries a spring. The latter is compressed when the blade, which was originally home, is burst open, and then forced back into its normal position. A blade equipped with such a device cannot be operated manually in situ.

The second method of automatic point operation by the train itself is used by the *Czechoslovak State* (fig. 2) (Builders : The Vitkovice Mines and Steel Works Co., Moravska Ostrava, 10.).

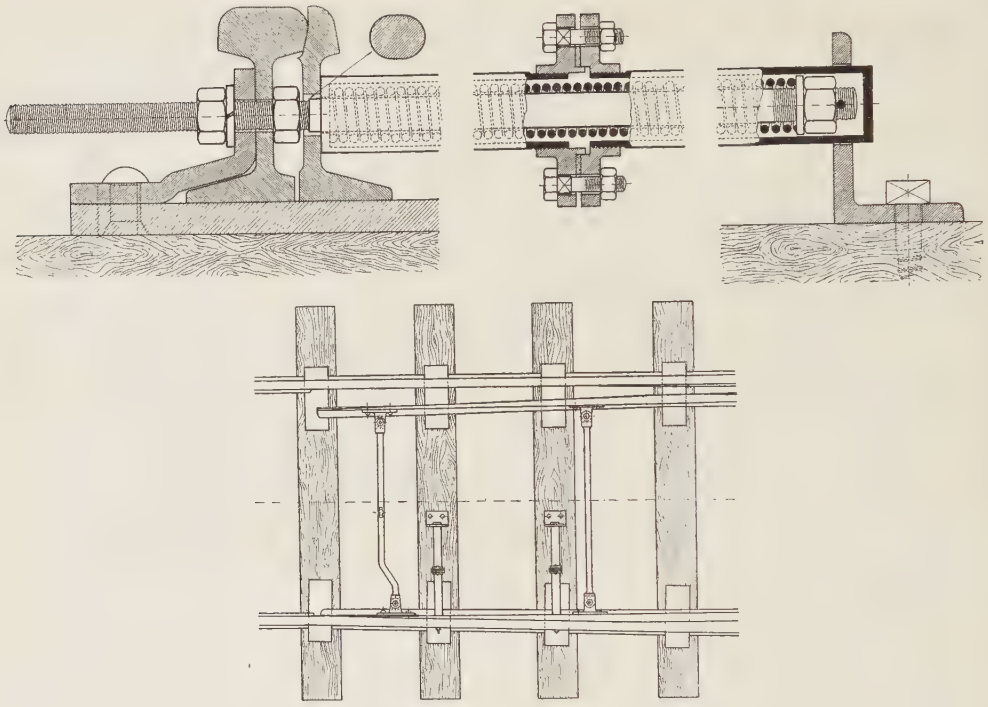


Fig. 1. — Automatic point operation by the trains running over switches trailing. *(Netherlands Railways).*

The device is installed outside the track, on the extension of the front connecting rod. This extension carries a a vertical anchor-shaped jaw which is connected to a counterweight forcing the points back into their normal position after they have been burst open when run over trailing.

The counterweight can be reversed from the left to the right, so that the points can be changed permanently if they have to be taken facing.

The third system is that of the *Paris-Lyon-Méditerranée Rys.* (figs. 3, 4 and 5).

This system is based on the principle of the spring switches with tongues built in at the heel. When taken facing, the blades move on inclined sliding plates. A counterweight facilitates the points being forced back into their normal position (see fig. 4). By means of a special key (fig. 5) the following operations can be performed :

With the key in the A position, the switch can be taken trailing without being damaged, the counterweight restoring the blades to their normal position;

When the key is in the B position, the effect of the counterweight is cancelled (switch taken facing).

In our opinion, automatic point operation by the train itself is only possible on secondary lines and in the case of low train speeds.

The switch is a very delicate part of the track and consequently must receive very special attention, two points being particularly borne in mind : (1) the blade and the check rail must be in close contact when taken leading, (2) the maximum train speed to be authorised.

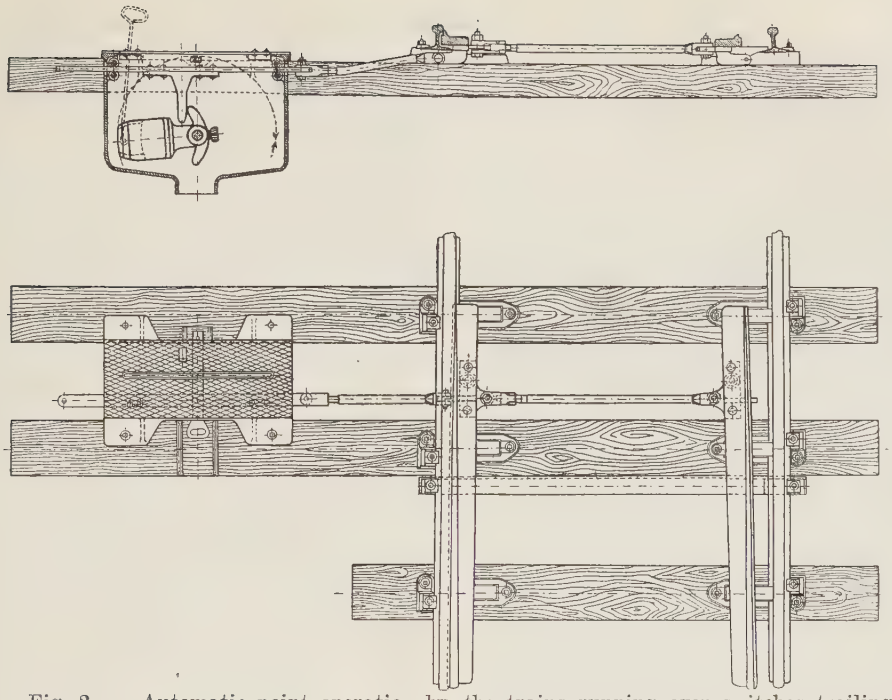


Fig. 2. — Automatic point operation by the trains running over switches trailing *(Czechoslovak State Rys.)*.

Figs. 3 to 5. — Automatic point operation by the trains running over switches trailing *(Paris-Lyon-Méditerranée Rys.)*.

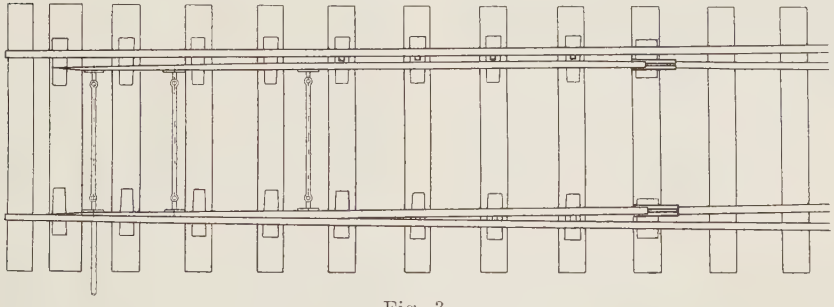


Fig. 3.

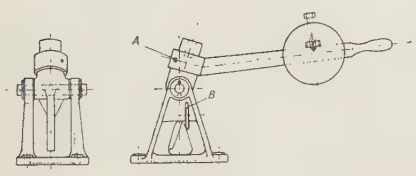


Fig. 4. — Operating device with counterweight.

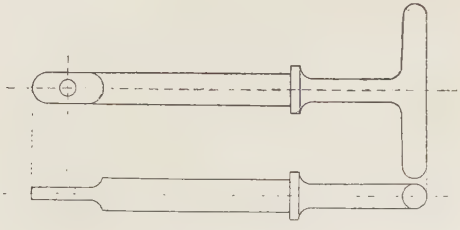


Fig. 5. — Key for fixing the counterweight.

Then too effect of the use of points and crossings built of heavy rail section on the running of light railcars should be studied.

The *lay-out of the lines* in passenger stations and goods yards, especially as regards the number and useful lengths of the shunting roads and crossing loops depends on the working requirements. The length of the sidings is 80 to 600 m. (about 260′ to 1 700′). Most of the Railways have a single siding in stations.

The *permanent way equipment* is in some cases standardised and in others materials recovered when relaying main lines are used. This latter method is very economical, especially in the case of Railways operating both light traffic lines and main lines. This method also results in uniformity of standards, reduced stocks and fewer types of materials. Track maintenance is easier and cheaper, apart from the possibility of vehicles with higher axle loads, running over such track, the economic advantage of which cannot be overestimated.

Therefore, most of the Railways favour this method. A number of narrow-gauge Railways using rails of different sections favour standardisation of the permanent way materials, and this cannot be too highly recommended.

* * *

CHAPTER V.

Substructure.

Wood, concrete, or more often barbed wire fencing is used at the stations and near level crossings on about half the Railways covered by this report. The question of fencing is undoubtedly bound up with the density of population near the railway or the proximity of estates or grazing lands to the railway.

The *dimensions of the formation* are given in the table. The data show that the width of the bed is not governed by the gauge in all cases. For example, on one metre-gauge Railway, the formation is 4.70 m. broad, i.e. wider than on most standard-gauge lines.

The bridges are built of different enough materials; the small-span bridges are steel and the large-span structures of masonry or concrete. In countries in which there is plenty of wood, this material is used.

In principle *level crossings* on light-traffic railways are not protected, the exception being much used level crossings (as in towns and near densely populated areas), or those where visibility is poor. The table shows when gates or automatic crossing signals are used, on lines of the different gauges.

In view of the growth of road motor traffic, the railways were asked if the new safety equipment at level crossings was provided or installed at the cost of the railways or if subsidies were received from the State, motor clubs, users, etc. In most cases the railways bear both the capital and maintenance costs of such safety devices at level crossings. One Railway has drafted an agreement with its Government, according to which the capital costs of the installations would be met by the authority maintaining the public roads in question, and the working and maintenance costs by the Railway.

We entirely agree with this point of view; the railways should not be burdened with the cost of this equipment, seeing the conditions on the railways are not altered as much as those on the highways; the latter have generally been modernised at the cost of the State, who thus provided the means for considerably increasing the speed of road vehicles.

In our opinion, up-to-date equipment to increase the safety at level crossings is chiefly installed in the interests of road motor traffic. This should determine the way expenditure on such installations, and their operation and maintenance, should be borne.

As a rule *halts* are provided at the cost of the Railways; on 5 railways the users contribute to the capital cost of the *halts*, and on 2 European railways the users have to meet the said cost. Although it can be stated that the Railways ought to attract customers, and therefore install halts at their own cost, on the other hand it may be said that in some cases the demands of interested parties as regards halts can be met suitably by requiring them to contribute towards the cost.

* * *

There is a very wide variation in the *loading gauges*. As however the Railways consulted have not all sent any complete data on this subject, we are not able to produce any detailed information.

* * *

CHAPTER VI.

Lay-out of passenger and goods stations

(including buildings).

The *platforms* are almost always uncovered on lines with little traffic. In a few rare cases glazed iron shelters are provided.

In some cases the platforms are raised 0.35 to 0.80 m. (1′ 1 3/4″ to 2′ 7 1/2″) (on the average 0.76 cm. = 2′ 5 7/8″) above the rail level.

As regards *station buildings*, especially as regards the dimensions, the various railways have given the following information :

(*a*) offices : 2.5 × 3.5 m.; 3.5 × 4 m.; 4 × 5 m. i.e. about, about 20 to 30 m² (215 to 320 sq. ft.);

(*b*) station-master's office : 15 to 20 m² (160 to 215 sq. ft.);

(*c*) rooms for service purposes : about 15 to 20 m² (160 to 215 sq. ft.);

(*d*) waiting room : 20 to 40 m² (215 to 430 sq. ft.), or according to requirements;

(*e*) cloak room : 10 to 20 m² (107 1/2 to 215 sq. ft.).

The sizes of living houses and other buildings depend on operating necessities as much as on the climate and the possibility of providing living accomdation (for example in colonies).

Only four railways use covered-in turntables. The other railways use either open turntables or shunting triangles. At junction stations the turntables belonging to the main-line Railway are used. Whilst most of the Railways are in favour of open turntables, one colonial railway favours the triangle, pointing out that this method is very convenient as well as very cheap, and involves no special construction work.

Weighbridges, are in use at all junction stations, as well as at other stations where about 1 000 wagons are loaded yearly. At connecting points between two railways of different gauges, a common double-gauge weighbridge is used. One railway prefers electric weighbridges to the ordinary weighbridges, when at least 10 wagons are loaded daily.

No special installations are required in connection with the exchange of passengers at junction stations, as joint platforms are used. As regards equipment for transhipping goods, the latter are either transhipped by hand or by cranes. Six railways with different gauges use travelling trucks for transporting wagons.

* * *

CHAPTER VII.

Signalling equipment and safety appliances.

There is no uniformity in the replies of the Railways to this question, and consequently no instructive information could be prepared therefrom. The re-

plies can be briefly summarised as follows :

Some railways call « fixed signals » signals with one indication although such signals cannot be included in the term signal in the narrow meaning of the word. Signals with at least two indications are provided at the larger junction stations. Caution signals are only provided in a few cases, as for example when repeating signals protecting the entrance to such stations.

Mechanical signals lighted by paraffin or oil lamps are in general use; in a few cases electric lamps are used. Daylight signals are very rarely used. Some railways consider mechanical signals are more positive in operation and cost less to work and maintain than day light signals which have to show the signal indication at all times.

Primary batteries are very rarely used by these Railways for signal lighting, although in our opinion this method, in view of the extraordinary progress being made, offers the possibility of effecting economies.

On most Railways requirements as regards the signals and safety devices are based on the rules laid down by the Government Inspection Department, and also on operating needs.

On 11 Railways the points are interlocked with the signals, especially at junctions in the open roads, and at junction stations. —

The safety installations on such lines are relatively simple. The points, especially those leading into the stations, are operated on the site and are locked or padlocked. In very few cases are the points operated from a signal box and this only in the most important stations, where the points leading into the station are mechanically operated.

On one European electric railway the points are mechanically operated; this railway also uses electric block instruments.

Automatic block is not in use on any light-traffic railway.

No Railways answered the question as to the minimum yield (as a percentage of the invested capital) of central interlocking frames. We think a decision should be come to on the provision of such operating mechanisms, either to increase the capacity of the stations quite apart from the question of increased safety, or to reduce the operating costs, i.e. to reduce the number of pointsman's posts. In the latter case we think the economy effected should at least counterbalance the interest on the capital invested plus amortization charges.

Headway between trains and operating methods.

On light-traffic railways the trains are run either on time intervals (4 railways) or on distance spacing. In the latter case a train is only allowed into a section when the previous train has cleared it (absolute block). A few railways use the permissive block (combination of the absolute block and the time interval headway), i.e. a train can pass a signal at danger after standing at it a few minutes, although it still remains at danger.

Four railways use the train token system under which no train can enter a section without the token (tablet, or staff).

Some railways work on the shuttle system, in which the line is worked by a single train running backwards and forwards.

Most of the railways use the manually operated block without interlocking, under which system the trains are controlled by telephone or telegraph.

Two railways use very successfully the train dispatching system, with which remarkable operating savings can be obtained. In this connection we would refer to the local lines of the *Czechoslo-*

vak State Rys. on which a method known as the « Simplified train dispatching system » is used. Under this system, the traffic on a line or section of a line is controlled by an employee known as the « controller » who is responsible for the train working over a line or section of line. This employee controls the working from a station, which is in telephonic communication with all the stations on the line. As there is no supervisory staff in the stations to dispatch the trains, all train guards have to obtain their orders from him for any alteration in the timings or the sequence of the trains. The train staff work the points in the stations.

The annual savings on staff obtained on the *Czechoslovak State Rys.* from this simplified train dispatching system amount to 6.5 million Czechoslovak crowns, on 4 150 km. (2 579 miles) of line.

* * *

CHAPTER VIII.

Telegraphs and telephones.

The light traffic lines are provided with much simpler intercommunication equipment than the main lines. As a rule the telegraph or telephone is used, the wires being run overhead. On most of the railways, double telephone wires are used. Iron wire 2.5 to 5 mm. (0.1″ to 0.2″) in diameter or copper wire 1.6 to 3 mm. (0.063″ to 0.118″) is used for the conductors.

Copper wire has better conductivity and a longer life than iron, a smaller diameter can be used, and therefore preference should, in our opinion, be given to copper.

Moreover, savings can be effected on the poles carrying the conductors. For example iron wire of 4 mm. (0.158″) diameter can be replaced advantageously by 2 mm. (0.079″) diameter copper wire, the specific electrical resistance of these two wires being almost the same. When copper wires are used, telephone messages are clearer and can be heard over longer distances than when iron wire is used, owing to the great tendency of iron to become magnetised and smooth out the electric currents.

No reply was obtained as regards the limiting values at which the telephones would work when the insulation factor of the line has fallen. We think the selective call telephone meets conditions best, as it works reliably even when the absolute insulation factor of the line has fallen as low as 10 000 ohms. Moreover, with selector telephones a greater number of instruments can be connected on the line.

The telegraph posts are wood or steel (old rails). Some Railways have run three telegraph and telephone lines. One Colonial Railway uses simultaneous high-frequency telegraph and telephone communications over a single conductor thus multiplying the communication facilities between the various posts along the line.

Wireless telegraphy is used on two Railways, with very satisfactory results. One European Railway has introduced wireless telegraphy on some small sections. Another Railway (colonial) uses wireless telegraphy to make good any failure in the conductor.

Out of the 36 Railways which replied to our questionnaire 14 have only one single means of communication, and the others have two.

Most of the railways in question use telephones.

Most of the telephone instruments are of the magneto type and are connected in parallel. Only one European Railway uses loudspeaker telephones.

The maximum number of telephones on an individual line is from 15 to 22. Selector telephones are used on two European Railways, one using the system with individual selective call. In this latter case, the telephone line is

divided into a number of independent sections according to traffic requirements. If a station on one section wishes to communicate with a station on another it connects through by manipulating the calling disc as prescribed. The two sections are then interconnected automatically by induction. One advantage of this arrangement is that if the insulation of one section is bad, the defect is limited to the section in question, and the other sections are not affected.

The telephone lines of light-traffic railways are connected with those of the main lines at connecting stations on five European Railways only.

In order to effect economies, the use of primary batteries can be recommended for telephone work as they require very little attention (for example, cells with air depolarisation).

The arrangements between the Railways and the Post Office as regards the joint use of telegraph poles vary. Two European Railways use the State telegraph poles free of charge, and some Railways pay for the use of the Government telegraph lines. Three railways have to pay the Post Office for running the railway wires on the Post Office poles.

The Post Office, on its side, carries its wires on railway poles, either on payment (one Railway) or without charge (5 Railways). In the other cases the Post Office runs its conductors on its own poles.

* * *

CHAPTER IX.

Recommendations of the Railways.

The general question propounded at the end of our questionnaire as to the possibility, in the opinion of the Railways, of reducing the fixed plant and the operating costs by other means directly or indirectly connected with the object of Question XIII has not brought in any definite reply.

One railway favours motorisation of the traffic, i.e. the substitution of railcars for steam trains.

Other interesting points of view put forward are as follows : One European Railway supports the point of view that steam traction be maintained for goods trains, and passengers be carried by road motor vehicles except on Sundays and holidays. One Colonial Railway Company expects a reduction in track maintenance cost by conveying flying gangs carried to the work in motor trolleys or light lorries. Most of the Railways favour the use of railcars.

In this respect, we think it opportune to draw up a comparison between standard steam train operation and railmotor car operation.

The *advantages* of railcars may be stated as follows :

(1) Immediate availability of railcars (no lengthy preparation is needed).

(2) Lightness and flexibility, hence higher working speeds, shorter journey times, and more frequent stops.

(3) Lower working costs (one-man operation, cheaper fuel).

(4) Faster and more frequent services.

(5) Owing to the lower axle loads, railcars operated on main lines can generally run on local lines. Passengers can thus complete their journey without changing off the main lines over the light railways.

The *drawbacks* of railcars are :

1. Limited capacity (fewer seats available).

2. Engine failures in service, which means replacing the railcars by steam trains (higher operating costs);

3. Railcars are less comfortable than the ordinary trains (separate compartments, heating, etc.).

No Railway is considering other changes to reduce the fixed plant. Some of them point out quite clearly that the fixed plant is already reduced to the minimum and that any further reduction would be difficult to carry out, without endangering safety and reliable working.

It may be said that so called light-traffic lines were built everywhere as simply as possible. When analysing all the factors which could affect the first cost, operating and maintenance costs, attention should be given to begin with to wear of the equipment in service and its periodical renewal. This refers especially to the permanent way, which was dealt with in Chapter IV.

* * *

Conclusions.

As shown by our report, the savings which can be effected on the fixed plant still constitute a big problem. Although the endeavours made to attain this object are limited, especially by the need there is to safeguard the safety of the traffic, the solution still depends on other circumstances.

We think that not only the first costs, but also the operating costs which are recurrent, should be brought into account as their influence on the decision to be taken is very great. It can be said that from the general point of view an economic service can be given by the following methods :

(a) *Directly :*

1. by adopting a lay-out (location) that will entail the lowest possible operating costs;

2. by equipping the line, especially as regards the track, in such a way as to require the least maintenance (heavier track, welding rails);

3. by not mechanising the work in cases when the staff have to be on duty for other reasons;

4. by adopting the point of view that State or other authorities, or users should bear the first cost of equipment adopted in the public interest, or not exclusively required for railway purposes (for example safety equipment at level crossings);

(b) *Indirectly :*

5. by suitable operating methods;

6. by introducing such economical methods in the traffic department as require the least equipment and the smallest staff.

We can sum up briefly the tendencies of the railways to lower working costs on the whole as follows :

The working must be made as scientific and economical as possible, taking full advantage of everything practice and technical progress has to offer, especially all methods and equipment offering better conditions as regards not only savings, but also traffic acceleration and increased safety.

In order to effect the largest savings, the safety equipment should be such that it can be operated in the shortest possible time over the largest area (central interlocking frames) the human factor being reduced to a minimum. Whilst the latter principle is most important, it must not be applied at the expense of safety.

In order to arrive at the best results as regards the analysis of the problem, in which all the Railways are interested, we feel this would be best attained by comparing the conditions on all railways. This means that the whole of the Railways should answer the questionnaires sent them.

We are persuaded that in the interest of all Railway Companies more valuable and more instructive results would be obtained in this way.

[625. 17]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

13th SESSION (PARIS, 1937).

QUESTION III.

Methodical and periodical maintenance of : 1. metal bridges; 2. signals; 3. metal supports carrying the contact wire on electric railways.

Organisation. — Working methods. — Materials used.

REPORT

(Netherlands and Colonies, Germany, Belgium and Colony, Luxemburg, Denmark, Norway, Sweden, Finland, Poland, Austria, Hungary, Switzerland),

by Th. W. MUNDT,

Ingénieur en chef des ponts du service de la voie, Netherlands Railways.

The present report deals with the various subjects included in Question III, as regards the Austrian, Belgian, Danish, Dutch, Finnish, German, Hungarian, Norwegian, Polish, Swedish and Swiss Railways, including the Railways in the colonies belonging to these countries.

1. Methodical and periodical maintenance of metal bridges.

Organisation.

Maintenance work and new construction under one single authority is encountered about as frequently a separate organisation of these two departments.

In certain countries, in which maintenance and new construction are carried out by a single service, a special constructional bureau is created when it is a question of important new works.

In most of the important Companies, the System is subdivided into maintenance areas which attend to general maintenance as well as that of tracks and metal bridges.

In certain Companies, maintenance of metal bridges is attended to by a distinct subdivision.

As a rule, the Companies have in each central regional operating bureau, a division which is specially entrusted with maintenance and periodical inspection of metal bridges. In such cases a specialised bridge inspector is entrusted with a daily inspection of such. This inspector has a gang of bridge workmen under his orders.

The engineer appointed to look after routine maintenance structures is also responsible for maintenance of the operating appliances of movable bridges worked by hand. Maintenance of the electrical operating appliances is

placed under the control of the electro-technical branch of a special division of the Mechanical Department.

Execution.

Periodical maintenance of metal bridges is carried out, according to circumstances, at intervals of 2 to 6 years, according to the importance of the work, and those Companies which make a distinction between a thorough inspection and ordinary inspection arrange for a thorough inspection to be made every 5 years.

The way general maintenance and painting work are carried out differs considerably from one Company to another, whether it is done by the Company itself or by contract. It may be pointed out that Railways having special gangs of bridge workers prefer to have the work done by their own staff.

There is usually between scaling, painting with red lead and re-painting a lapse of 5 to 6 years; but in countries where sea-air is not to be feared the period usually averages 10 years.

The seasons during which re-painting work is done is usually the end of spring, summer and early autumn in countries where low temperatures often occur, when the latter exceed + 2° C. (35.6° F.) and during the dry season in tropical regions.

As a rule paint work is done directly after scaling and the application of red lead.

On most Railways the surfaces which are still in a good state after scaling and applying a layer of red lead are not re-painted, unless the general aspect of the structure as regards painting is bad, in which case a layer of paint is applied everywhere, when the second coating is put on.

On electrified lines with overhead contact lines painting is done during the daytime and the current is cut off between the passages of trains; or else the current is cut off during the night, painting is then done around the contact wires during the night and the remainder in daytime, or again the current is cut off during the night and the whole of the re-painting is done during the night.

It is advisable to have a watcher constantly present and to earth the line on either side of the bridge.

Working methods.

For repairs to metal substructures, both compressed air and electric tools are used and it goes without saying that electric welding is being more and more used, as also for the strengthening of bridges.

For checking the welds the *German State Railways* have their own X-ray plant; the other Railways which use this system make use of appliances belonging to contractors or have at their disposal those belonging to official organisations.

In addition to being done by hand, scaling is also done by means of derusting-hammers, chisels, brushes, etc., as well as with pneumatic and electrical appliances, specially designed for this purpose, whilst in certain cases sand-blasting is used for bridges already in existence.

Some Companies prescribe spray painting or at any rate allow it to be used, but only in cases where the paint to be applied has no lead base. Spray painting with a finishing coat by brush, is also resorted to.

Opinions vary as to the comparative value of brush-painting and spray-painting and also as regards the savings that can be obtained by spray painting. The saving largely depends on local wages.

Installations.

In the case of most companies, large bridges are provided with inspection

trolleys fitted beneath the bridge, and also used for the painting, and (or) with platforms.

Materials.

For existing bridges as well as for new bridges a layer of red-lead is generally used as a priming coat; only a few Companies use iron oxide.

As part of the maintenance work, derusted parts are usually given a second coat of red oxide and after that 2 coats of paint, as is customary for new structures.

For the outer coatings, both red lead mixed with ordinary linseed oil and red lead mixed with « standolie » (linseed oil thickened by heating) are used. Paints having zinc as a basis are not used.

For the second coating an aluminium oil paint is even used; on the *Dutch East Indies State Railways* both coats consist of plain aluminium paint; the flooring is given an additional coating of iron oxide, whilst structures immediately near the sea are given an additional coat of paraffin varnish.

For parts of bridges exposed to moisture bituminous paints are also used.

Tests with liquefied metal spray painting are now being carried out in Germany and will also be undertaken in Belgium.

Most companies use exclusively coated electrodes for electric welding, except the *German State,* the *Finnish State* and the *Dutch East Indies State* Railways, who use uncoated electrodes as well as the others.

General remarks.

Setting aside the influence of the design of structures on maintenance work, it appears that the manner in which the steel parts of the structure have been handled during the building of a bridge, before prime coating, has an important effect on subsequent maintenance work required by the structure.

If the steel is not carefully handled, it rusts, with resultant cracks in the coatings of paint and the usual consequences, in spite of the best elastic, sun-resisting weatherproof paints being used.

In this connection the question has been raised as to whether by derusting of new steel, either by sand blasting or by chemical treatment, periods between re-paintings will be lengthened. With regard to this point, the *German Railways* and the *Austrian Railways* reply in the negative, whilst *Denmark, Switzerland* and *Holland* reply in the affirmative and Norway does not appear to have formed an opinion.

The *German Railways* even go as far as to state that they think, on the contrary, the adhesion and life of the paint are lessened, and they advise leaving intact the mill scale instead of destroying it by sand blasting or by a chemical process.

Seeing that Germany is a steel producing country and that the metal is used shortly after rolling, and that consequently after its being worked up and mechanically derusted the mill scale is left practically intact, the question arises as to whether erection, drilling and other subsequent operations do not cause a detaching or destruction of the mill scale which, in their turn, render the metal liable to rusting.

In view of its possible effect on subsequent painting and maintenance work, the question of the preservation or destruction of the mill scale is worth being carefully studied, as well as the choice of the various methods of removing the said scale from the point of view of the life of the paint, seeing that bridge repainting is one of the heaviest items of expenditure.

If there were any certainty that rust could be practically prevented from developing beneath the paint, there should be no objection to even a high price being paid for a really waterproof

paint, not only in order to lengthen the periods between two paintings, but also to reduce to a strict minimum the costly derusting work.

That would mean, in fact, maintaining the impermeability of the outer coat, which would constitute an ideal state of affairs, which can unfortunately not be attained, but which should be approached as near as possible.

We would mention here that the usual methods of removing the mill scale consist of sand blasting, exposure to the open air or a combination of the two methods.

The objection to sand blasting is raised that it is difficult to decide how far the operation should be pushed in order to obtain complete elimination of the scale. To the method of exposure to the open air, there is the objection of causing a rough surface, which occurs equally with too deep sand blasting and which, in the opinion of many, is an obstacle to intimate penetration of the prime coating of red lead which shuts in moist air, which in turn gives rise to rusting. Against this theory, there is the opinion of others who maintain that, as long as the steel is not first coated with linseed oil, its roughness supplies an excellent adhesive surface for the prime coating of red lead and that, if the paint is carefully applied, all the hollows are effectively filled by the latter.

Suggestions have recently been made to remove the mill scale by chemical processes and in particular by the use of phosphoric acid.

Briefly, this process consists of an application of hot wax containing phosphoric acid, followed by dipping for at least 5 minutes in a hot solution containing from 0.5 to 2.5 % free phosphoric acid and 0.3 % of iron. After which there forms on the steel a very thin layer of phosphate of iron. The priming coat of red lead is then applied whilst the metal is still hot.

The composition of the paints used is not stated : that would lead us into too many details and appears to be superfluous in view of the present state of paint technique.

In order to keep maintenance costs as low as possible it appears justified to stress the fact that not only are designing engineers not sufficiently informed daily as to difficulties caused during maintenance work by constructional peculiarities but also that they should preferably be directly responsible for maintenance, or if this proves difficult, at any rate indirectly.

Seeing that painting of metal bridges absorbs the greater part of moneys set apart for maintenance, the question as to whether the work should be carried out by the Railways themselves or by contractors, appears to deserve closer study.

Let us first look into the question of *descaling existing structures.*

If this work is undertaken for a fixed sum the chance of having the work satisfactorily done may be considered as slight. A contractor is not in a position to estimate the method of formation of rust and the extent to which it has developed before the contract is placed. That only becomes possible when the derusting work is actually proceeding. Owing to competition, he is obliged to quote a low price and in order not to exceed the contract price, he will work hand in glove with the workmen who, by that very fact, will not carry out the work under the desirable conditions. However strict the supervision may be, the superviser himself does not take an actual hand in the work, and cannot consequently judge as to whether the derusting is carried out thoroughly and conscientiously.

One should try to exclude the taking of profits by sub-contractors in such a way whenever it is possible, and try to keep such profits for the Company by having the work really well done : either

departmentally or by having the work paid for on a time basis.

The supervisor should above all make sure that the work is done at a reasonable speed, viz. he should try to prevent systematic « slacking ».

A workman who works indifferently knows what risks he runs and that he may expect not being taken on for another job.

Painting lends itself well to being contracted out.

A contractor knows the exact area to be dealt with, knows how many square feet of a given surface he can cover with a given quantity of specified material and can make a careful calculation of the work to be done.

Strict supervision is of prime importance in this case, but the effect of competition, when drawing up the tender, may still lead to defective or unsatisfactory work, in spite of strict supervision.

In the actual constructional work an official entrusted with its supervision is able to see, first, that each part is properly manufactured and then that the whole is satisfactorily erected. That does not apply to painting. A painted surface may have a satisfactory aspect and yet not conform to the Management's specifications, e.g. owing to insufficient thickness of the coat of paint — thus enabling the same quantity to cover a greater area — or to the use of foreign matters which reduce the cost of the paint, and so forth.

Supposing that all the constitutive matters of the paint are choice and that the paint itself reaches the site in sealed tins under the supervision of an official conveying it and that, after the day's work is done, it is placed under lock and key in a shed, there is still the risk that the painters may add something or other where the work is done. Analyses of samples taken from the painters' pots may act as a deterrent in this respect; it is difficult to say where the limit should be drawn with this system and there can be no question of searching the workmen before they start work.

Painting work carried out by the Railway's own staff does away with these accessory considerations and the Administration may be sure of obtaining the best possible work without its costing appreciably more than contractors' work, because the materials used are then purchased in large quantities by the Railway and at much lower cost prices than those obtained by third parties.

2. Methodical and periodical maintenance of signals.

Organisation.

Except in *Belgium, Germany* and *Sweden* a special department attends to the maintenance of signals. In Belgium the Signal Engineer is responsible for the maintenance of electrical installations whilst in Germany maintenance of signals is a task of the permanent way department, although the larger installations are maintained by distinct « Stellwerkmeistereien ».

As a rule the telegraph and telephone lines are also maintained by the divisions who maintain the signals. In *Holland* there are attached to this service, in addition, electric clocks, lighting, plant for working bridges, and central heating.

The organisation often consists in a division into districts which, as regards both the number of staff belonging to them and the length of the lines under their charge, differ considerably from one Railway to another. On the different Railways, the length of various lines in each district, considered as a relatively independent unit, varies between 15 and 200 km. (9.3 and 124 miles), the number of signal boxes varying between 7 and 350.

Method of operation.

The maximum number of mechanical levers is 293 000 (*Germany*) and the minimum number 1 100 (*Finland*); the number of electrical appliances varies between 50 000 and 50 whilst, among other systems of signal and point levers that can be mentioned, there are 2 700 electro-pneumatic in *Germany* and 230 in *Holland*.

Staff.

Per district, the number of mechanical levers varies between 115 and 5 000; the number of electric levers between 20 and 1 000 and the number of electro-pneumatic levers from 1 to 50.

As regards the number of maintenance inspectors in each district, the averages mentioned are from 1 to 5, each supervising individually an average of 7 to 50 signal boxes, which means that to each inspector there are assigned an average of 100 to 1 260 levers.

These inspectors thus have 4 to 40 subalterns under their orders, the latter being in most instances divided into 3 classes hierarchically apportioned in the ratio 1 : 1 : 2 or also 1 : 2 : 1.

Working hours.

As regards the working hours of these employees they are generally 8 hours a day, including as a rule time to reach the site and return from same. There are, however, numerous exceptions, both as regards the maximum number of hours of work per day and the regulation as regards getting to the place where the work is carried out, and returning. Thus, for instance, in *Austria* travelling time is not taken into account, when there is an absence of less than 13 hours; in *Denmark* and *Hungary* each hour of travel is reckoned as half an hour's work; in *Norway* this is only admitted when travelling and working hours exceed a total of 8; in *Holland* a maximum of 8 1/2 hours is the rule, including travelling time, and in the *Dutch East Indies* 10 hours; in *Poland* the working hours for maintenance work are not restricted; in *Sweden,* when the distances travelled are over 7 1/2 km. (4.65 miles), the travelling time is counted as work-hours; whilst in Switzerland hours travelled are reckoned as so many half hours work, the maximum to be accomplished being 7 hours in winter and 9 in summer.

Per week, this means in general about 6 working days of 8 hours, or 48 hours, during which working periods of over 10 hours cannot succeed each other, except in the *Dutch East Indies* where the maximum, in this respect, is 13 hours.

If these maximum periods are exceeded, they are made good in a week to a month's time by so many days off duty.

If repeated calls have to be made upon breakdown gangs in case of disturbances, a maximum of 10 hours a day is not exceeded.

Training schemes.

Maintenance of mechanical and electrical signals is generally carried out by the staff who have to work them, and thus the question of a theoretical training scheme does not arise as a rule.

In *Austria* there was initiated in 1936 a system of one year's professional training in the workshops, followed by a one-month course and winding up with an examination. Promotion is both according to seniority of service and by selection.

Rules and regulations.

Headquarters are usually kept informed, by means of daily or weekly reports, of all the difficulties encountered by signal inspectors. These reports are sometimes transmitted by telephone. It is only in certain Administrations that regulations laying down the functions of each official are published.

A report as to the condition of the

apparatus is usually not required. In *Germany, Finland, Poland* and *Switzerland* these reports are made out yearly; in *Sweden* every three months and in *Austria, Belgium, Hungary* and the *Dutch Indies* once a week for certain particular cases. Periodical meetings of signal inspectors and the signal engineer are not as a rule arranged unless it is necessary.

A control as to the knowledge of regulations by mechanics and electricians is generally carried out and repeated after a certain lapse of time.

Lists of the addresses of maintenance staff are not posted in the signal boxes, Station masters are usually in possession of such lists.

Disconnection of levers and testing interlockings.

When temporary disconnections of interlockings and connections are made, a written communication describing the operations that are to take place is sent out to all the persons concerned and has to be signed by guards and station masters. By means of special signs and by the sealing of levers, places where the connections are interrupted are pointed out.

For the regular inspection of sites most companies give instructions to the electrical or mechanical worker, made out in the form of a given programme and in accordance with which the frequency of such inspections varies from one to twice a year.

Interlocking plant is usually cleaned and oiled when required.

Ordinary linesmen are not allowed to take down any lockings although in certain cases and on certain Railways this is permitted under the supervision of an authorised station employee.

Changes to mechanical interlockings are usually made by fitters, on the instructions of an inspector. Headquarters know of this beforehand and inform those concerned.

Only a few Companies arrange for a periodical inspection by signalmen.

Spare parts.

As a rule, maintainers keep a small stock of spare fittings for daily requirements. This stock is based on requirements for about 2 months and is only kept in the lower part of signal boxes when the latter are very large : in such cases the district inspector has to supervise them.

Periodical inspection of good luminosity of signals is carried out by certain Railways and in such cases is made twice a year, in winter in the morning towards the end of the period during which the signals are lighted. In addition, remarks made in this respect in the reports of locomotive staff, are taken into account.

On many Railways maintainers have bicycles at their disposal, which are the property of the Company. It may be pointed out that in Holland the staff use their own bicycles and receive, a sum of 6 florins per annum for depreciation and compensation.

When the men have to travel long distances petrol-engined inspection trolleys seating 2 or 3 persons are often provided and maintainers have assistants if required. Most Companies have no written instructions for such employees.

Detector slide clearance.

Standard clearance or tolerance for the notches in detector slides or in the stretcher rods are not laid down in a precise manner as a rule.

In Germany a clearance of 2.5 mm. (3/32″) is prescribed in detector slides and 30 mm. (1 3/16″) for connecting rods. In Austria the whole of the clearances must be within 1 and 3 mm. (5/128″ and 5/64″). In Switzerland, according to constructional requirements between 1 and 2 mm. (5/128″ and

5/64″), in Belgium 5 mm. (3/16″) is allowed for the switch and 1/2 mm. (5/256″) for the lock; in Poland the corresponding figures are 5 mm. and 2 1/2 mm. (3/16″ and 3/32″), whilst in the Dutch Indies 4 mm. (5/32″) is prescribed. Finland, Hungary, Norway and Holland fix respective clearances of 3 mm., 1/2 mm., 2 mm. and 3 mm.

A standard gauge to which electrical detection of points must conform is not in general use. Often a steel wire of a desired thickness say 5 or 4 mm. (3/16″ or 5/32″) diameter, is used. The largest clearance is : in *Germany* 2.5 mm. (3/32″), in *Belgium* 5 mm. with the point closed and 2.5 with the point open; in *Denmark* 3 mm. (1/8″); in *Finland* 5 mm (3/16″) and in *Hungary, Norway, Holland, Dutch Indies* and *Sweden* 4 mm. (5/32″). Statistics of the use of this gauge are not kept everywhere.

Signal wires are often enclosed in conduits. The latter are made of iron or galvanised sheeting, or concrete covered by a plank, or else entirely of wood.

Tools.

All linesman's tools are placed at the disposal of maintenance men, as also other more important equipment, which is sometimes worked by air or oil pressure.

Motor-driven portable appliances are only at their disposal for drilling. As a rule, a list of tools has to be kept.

Types of signals.

To show that the track is clear, mechanically operated semaphore signals are usually raised to 45° in the upper quadrant. For these signals both ladders and small step-ladders are used; but when, as in the majority of cases, lanterns that can be hoisted are used, no platform is provided on the semaphore post.

The maximum distance at which mechanically operated signals are situated from signal boxes varies from 400 to 2 000 m. (1 312 to 6 560′); this distance is mostly 1 100 to 1 200 m. (3 610 to 3 940′). Periodical inspections of mechanical and electrical appliances are made on most systems by the section chief. No statistics of these are kept. As regards insulation of electric conductors periodical inspections are only made when necessary.

Electric signal lamps.

As a rule no record of the total number of hours during which lamps are lighted is kept. In *Germany* the lamps of stop signals and of distant signals are renewed annually.

In the case of numerous Railways, lamps are underrun. Instruments that are everywhere placed at the disposal of staff are ammeters, voltmeters and ohmmeters.

Disconnecting wires for taking measurements is not allowed everywhere.

Point rodding and wires.

In cases where a rigid transmission is used, tubular rods are used; in most countries double galvanised wires are used.

Tubular rods are repainted periodically, as required or every 5 to 8 years. As the priming coat red lead is used, on which several coats of oil paint are placed. For certain underground parts bitumen is also used.

Signal arms.

The final coating of lacquer-paint is usually applied to signal arms once the signals are erected. Wooden signal arms are rarely used. As a rule iron arms are used and certain Railways have them enamelled. All sorts of compositions are used for paints.

For cleaning signal arms, sand blasting is nowhere used, but steel brushes and soap. Other chemical means are not used. If the semaphore signals or the light signals are repeated electrically in the signal cabin this is done on the « open circuit » system (in Switzerland : closed circuit), with conductors (often cables), insulated in such a manner that earth contacts cannot cause false indications being given, thanks to the use of safety appliances judiciously selected.

The method of installing the power supply varies a great deal.

Track circuits.

A testing table for each track circuit is kept by a number of Companies; some others do not use it. When such a table is kept its periodicity varies from three months to a year.

For track circuits no admissible minimum shunt by trains is prescribed. In Germany they reckon on 4 Ω and the length of circuit is regulated accordingly. When this figure cannot be complied with, the circuit is made shorter.

The lengths of track circuits varies from 800 to 2 100 m. (2 625′ to 6 890′). In the old exterior types, insulated wooden joints are still used; in the newer ones iron is generally used with insulation by fibre or bakelite, welded bonds and bolts. These welds are maintained in *Belgium, Denmark* and *Switzerland* by the signal staff; in *Finland, Holland* and *Poland* by the permanent way staff; in *Germany* and *Sweden* by both.

The track circuit relays are inspected at given intervals according to requirements, varying from 12 to 18 months.

Electric locks.

According to the make, electric locks are placed in front of or behind the box and above or below the flooring, but in most instances behind and above the latter. The locking methods vary considerably.

Circuit makers.

If circuit makers are used for signals the track circuit is cut off after a movement of about 10° when on the « open circuit » system, whilst with the « closed circuit » system it is only re-established at the end of the movement.

Cleaning of motor-operated point machines.

The cleaning of motor-operated point machines is only done during periods when no trains are running.

For the cleaning and lubrication of contacts it is everywhere forbidden to the maintainers to operate the mechanism without having previously put out of action the control circuits of the points concerned and the locking of the signals; in addition, the maintainer must inform the signalman in the box concerned.

Trickle-charged accumulators.

As a rule the maintainer does not receive instructions to cut off the charging current and let the battery feed directly, in order to avoid an excess charge in trickle-charged accumulators.

Token instruments.

The use of token instruments is not mentioned by any of the Railways consulted.

Materials used.

The selection of materials is made according to the nature of the structure.

The lower parts, which are subject to intense wear, are usually made of steel. Electric welding is not much used.

Signal pylons are constructed on very varying lines.

In *Germany, Belgium, Finland, Hungary, Norway,* the *Dutch Indies* and *Sweden* much use is made of assembled masts; in *Austria* and *Holland* Mannesmann tubes are used; in *Hungary* and in *Holland* riveted iron plate tubes are also used and in *Switzerland* special rolled sections. The posts are generally repainted every three years; the figures quoted vary from 1 to 5 years. The composition of the paint varies greatly.

The oils used as lubricants also vary much. Waste oil is used whenever possible. Graphite is only used exceptionally as a lubricant.

Lamps for colour-light signals are nowhere renewed at given intervals. They are underrun 5 to 15 % in the day-time and 20 to 25 % at night-time. These lamps and the glasses and lenses are cleaned as required. In order to avoid the creation of phantom indications from outside reflected sources of light, recourse is often had to plain lenses with which this phenomenon does not occur. Only maintenance men are allowed to open the sides and covers of lamps (or light signals) during periods when no trains are expected.

As a rule, double-filament lamps are not used. The position of the filament is checked everywhere relatively to the device fixing the lamp in the socket.

Automatic train control.

The maintenance of automatic train control plant, cab or signalling apparatus is, in the case of the few exceptional Railways who use it so far, attended to by permanent-way staff as well as by signal staff, as far as concerns those parts which belong to the track equipment, and by the locomotive running and signal staffs as regards parts attached to the locomotives.

When they leave the sheds, locomotives are submitted to a braking test. This test is repeated monthly at the depot. In addition, the *Swiss Railways* order a daily test of the locomotive equipment to be made at the first distant signal in the « on » position encountered. Remarks concerning these tests are entered in a control book.

In the case of certain Railways, the track equipment is inspected daily. The regulations concerning inspections and the intervals between the latter are very dissimilar and vary according to the system employed. The use of a special printed form for reports regarding the functioning of the installation is not general. Maintenance is carried out by the ordinary maintenance staff.

There are so far no special orders in this respect, in as far as the latter are not included in orders referring to ordinary maintenance of electric locomotives (*Switzerland*).

The system used differs from one Railway to another; on each Railway there are also various systems, according to the kind of traffic. In Germany, on the « Fernstrecken » (*long-distance*) lines, the inductive and optical system is used, whereas on urban and suburban lines a mechanical system is used. In *Belgium* the railways use the Flaman system or the Teloc system (repetition of warning signal on locomotives); in *Switzerland* the railways use the Signum Wallisellen system (continuous current impulsion).

Centralised traffic control.

None of the Railways mentions the use of centralised traffic control installations.

Special equipment.

As a rule, only tools of standard make are used, suitable to the pecularities of the kinds of apparatus used.

3. Methodical and periodical maintenance of metal supports carrying contact lines on electric railways.

Complete replies to this chapter of the questionnaire have been received

from 12 railway administrations who operate electric railways by means of overhead contact lines, viz. the *Deutsche Reichsbahn*, the *Austrian Federal Railways*, the *Belgian National Railways Co.*, the *Danish State Railways*, the *Hungarian State Railways*, the *Norwegian State Railways*, the *Netherlands Railways*, the *Dutch East Indies State Railways*, the *Polish State Railways*, the *Göteborg-Boras Railway*, the *Swedish State Railways* and the *Swiss Federal Railways*.

Among these administrations, *Denmark* possesses the smallest electrified system, viz. 45 km. (28 miles), and *Sweden* the longest, with 2 600 km. (1 616 miles).

The greatest distances between supports are as follows :

Austrian Federal Railways	60 m.	(196′ 10″).
Belgian National Railways	63 m.	(206′ 8 1/2″).
Danish Railways	80 m.	(262′ 5 3/4″).
Netherlands Railways	70 to 75 m.	(213′ 3 1/8″ to 246′ 3/4″).
Dutch East Indies Railways	75 m.	(246′ 3/4″).
German Railways	65 to 75 m.	(229′ 8″ to 246′ 3/4″).
Göteborg-Boras Railway (Sweden)	60 m.	(196′ 10″).
Hungarian Railways	75 m.	(246′ 3/4″).
Norwegian Railways	60 m.	(196′ 10″).
Polish Railways	72 m.	(236′ 2 3/4″).
Swedish Railways	60 m.	(196′ 10″).
Swiss Federal Railways	60 and 100 m.	(196′ 10″ and 328′ 1″).

Organisation.

The Divisional Engineer of the Chief Mechanical Engineer's Department is responsible for maintenance of the supports in most instances, except in *Hungary*, *Sweden* and *Norway* where the Permanent Way Department is responsible and *Switzerland* where there is a special electrical service (Electrical Installations Service). In Denmark responsibility for daily maintenance has been hitherto attributed to the Central Bureau, but it will in future be delegated to the signal engineer (Principal Signal Engineer).

Staff.

The staff entrusted with maintenance of the overhead contact lines is, in addition, entrusted with maintenance of the supports. The number of hands per kilometre of track varies considerably, which is explained by the kind of supplementary work to be achieved.

The following are a few figures concerning this point :

	Men	
	per km.	*per mile.*
Deutsche Reichsbahn (German Railways)	0.13	*0.21*
Austrian Federal Railways	3	*4.8*
Danish State Railways	0.1	*0.16*
Netherlands Railways	0.3	*0.48*
Hungarian State Railways	0.19	*0.31*
Swedish State Railways	0.09	*0.14*

It should be pointed out here that in Austria and in Holland this staff, in addition, maintains the substations.

Inspection.

Supports are inspected in the following countries as shown below :

Austria	twice a year.
Belgium	once a year.
Germany	once a year.
Netherlands	once a year.
Hungary	4 times a year.

This inspection is made by the staff who maintain the overhead contact lines and their supports.

Types of supports.

In most cases the supports consist of special rolled sections (U and L). Various countries also use concrete supports (*Austria, Belgium* and *Germany*). In Austria and Norway wooden supports are also used. In *Belgium*, the *Netherlands* and *Switzerland* special sections of the Grey type are used on a large scale.

Composite supports are assembled, either by riveting, welding or bolting; the latter method of assembling is, among others, used in *Holland* for galvanised supports.

Foundations of supports.

As a rule supports are fixed in concrete foundations. When the soil is poor, recourse is had to special methods, The latter are :

in Austria : anchorages and pile driving;

in Belgium : pile driving;

in Germany : anchorages;

in Holland : pile driving for heavy supports, anchorages and foundations of slight depth but wide area which are fished under the substructure of the permanent way; use of portal frames;

in Hungary : driving creosoted oak piles;

in Norway : the use of wood framing;

in Poland : anchorages and the use of superposed concrete slabs.

In *Switzerland* and in the *Dutch East Indies* no difficulties have been encountered in this respect.

In most of the countries anchored supports do not require any additional maintenance except in *Poland* where such is the custom.

Painting.

Supports are painted as required. In *Germany*, on sections of line carrying mixed traffic they are painted, every 5 to 6 years, and on lines carrying only electric traffic every 7 to 8 years. In *Norway*, once every 8 to 10 years; in *Holland* once every 5 to 6 years; in *Sweden* once every 10 years.

Supports usually receive 3 coats of paint : the first of red lead, the two following coats of white lead. In the *Dutch East Indies*, 4 coats are applied, two of them being red lead.

In *Germany* and *Hungary* the painting is partly done by contract and partly by railway staff; in *Poland, Switzerland* and *Sweden* by contract; in *Hungary, Holland*, the *Dutch East Indies* and *Austria* by the Railways themselves.

For the cleaning of supports no mechanical equipment is used, nor electric, the work being done by hand.

Galvanised supports are used in *Austria* and *Denmark* and also, by way of experiment, in *Germany*. In *Belgium* and *Poland* the use of galvanised iron is restricted to the arms and brackets; in *Belgium* these parts are painted, in addition.

Metallization processes have been applied as a trial in *Germany* and *Austria*, without giving much result. That also applies to *Holland*, where zinc spray painting has been commenced on a large scale. All the supports so treated have had to be repainted.

Safety precautions during maintenance work.

Poles supporting elements under voltage at a sufficient distance can be re-

painted without it being necessary to switch off the current. As soon as work has to be carried out at distances below a certain minimum, the current is switched off.

In *Germany* the limit up to which work may be carried out is displayed on a poster; in *Austria* the attention of the staff is specially drawn to the danger to which they are exposed and a watcher is present; in *Belgium* supports can be entirely painted as the parts under voltage are far distant from the poles. In *Hungary* and *Norway* contact lines are put out of circuit and earthed during maintenance work.

In *Holland* the same precautions are taken as in *Austria:* when work has to be done in the immediate neighbourhood of parts under voltage the line is placed out of circuit and earthed; in the *Dutch East Indies* the current is switched off and the line earthed.

General remarks.

It will be seen from the foregoing that two methods have been used in attempting to avoid the troublesome work of maintenance painting of iron supports : either by metallisation after complete sand blasting, or by galvanisation.

Seeing that such manipulations require to be done in a workshop and that supports thus treated have to be transported to their site and there put into position on their foundations by means of apparatus, and then have their brackets and braces fitted etc., both of these methods are liable to cause deterioration before the actual erecting is finished.

This being so, it appears that metallisation consisting of an accumulation by spraying of fine particles of metal will not achieve the aim sought because an amorphous coating is very liable to deteriorate. Even if it were possible to carry out the erecting and various maintenance work without damaging the coating projected by the sprayer, the existing pores and tiny holes between the metal particles, which become filled with water and moisture, are bound to set up rusting.

Careful galvanising does not entail the same risks of deterioration or corrosion, at least over a number of years. The question as to how long such galvanisation will withstand corrosion can only be decided after many years' experience, and then only apart from prevailing local influences; but it is nevertheless certain that for a number of years derusting and painting can be dispensed with, and by that very fact the expenses inherent to galvanisation are largely recouped.

It is therefore clear that the use of galvanisation means reduced maintenance costs.

It must finally be remarked that the use of rolled steel sections for posts and supports does not only lead to a reduction of first costs, because erecting yards are mostly unnecessary, but also because their simple shape, making every part of them easily accessible, also means a saving in maintenance costs.